ELECTRIC WIRING

COPPER WIRE BRAZING FURNACE.
Rockwell Engineering Co.

ELECTRIC WIRING

INSTRUCTION PAPER

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ELECTRIC WIRING

METHODS OF WIRING

The different methods of wiring which are now approved by the National Board of Fire Underwriters, may be classified under four general heads, as follows:

1. Wires Run Concealed in Conduits.
2. Wires Run in Moulding.
3. Concealed Knob and Tube Wiring.
4. Wires Run Exposed on Insulators.

WIRES RUN CONCEALED IN CONDUITS

Under this general head, will be included the following:

(a) Wires run in rigid conduits.
(b) Wires run in flexible metal conduits.
(c) Armored cable.

Wires Run in Rigid Conduit. The form of rigid metal conduit now used almost exclusively, consists of plain iron gaspipe the interior surface of which has been prepared by removing the scale and by removing the irregularities, and which is then coated with flexible enamel. The outside of the pipe is given a thin coat of enamel in some cases, and, in other cases, is galvanized. Fig. 1 shows one make of enameled (unlined) conduit.

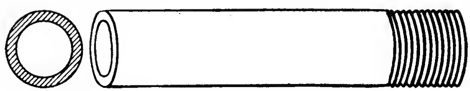

Fig. 1. Rigid Enameled Conduit, Unlined.
Courtesy of American Conduit Mfg. Co., Pittsburg, Pa.

Another form of rigid conduit is that known as the *armored conduit,* which consists of iron pipe with an interior lining of paper impregnated with asphaltum or similar compound. This latter form of conduit is now rapidly going out of use, owing to the unlined pipe being cheaper and easier to install, and owing also to improved methods of protecting the iron pipe from corrosion, and to the introduction of additional braid on the conductors, which partly compensates for the

pipe being unlined. The introduction of improved devices—such as outlet insulators, for protecting the conductors from the sharp edges of the pipe, at outlets, cut-out cabinets, etc.—also decreases the necessity of the additional protection afforded by the interior paper lining.

Rigid conduits are made in gaspipe sizes, from one-half inch to three inches in diameter. The following table gives the various data relating to rigid, enameled (unlined) conduit:

TABLE I
Rigid, Enameled Conduit—Sizes, Dimensions, Etc.

Standard Pipe Size	Thickness	Nominal Weight per 100 Feet	Number of Threads per Inch of Screw	Actual Outside Diameter. Inches	Nominal Inside Diameter. Inches
½	.109	84	14	.84	.62
¾	.113	112	14	1.05	.82
1	.134	167	11½	1.31	1.04
1¼	.140	224	11½	1.66	1.38
1½	.145	268	11½	1.90	1.61
2	.154	361	11½	2.37	2.06
2½	.204	574	8	2.87	2.46
3	.217	754	8	3.50	3.06

Tables II, III, and IV give the various sizes of conductors that may be installed in these conduits. Caution must be exercised in

TABLE II
Single Wire in Conduit

Size Wire, B. & S. G.	Loricated Conduit, Unlined; D. B. Wire
No. 14-4	½ inch
" 2	¾ "
" 1	¾ "
" 0	¾ inch or 1 "
" 00	1 "
" 000	1 "
" 0000	1 "
250,000 C. M.	1¼ "
300,000 C. M.	1¼ "
350,000 C. M.	1¼ "
400,000 C. M.	1¼ " or 1½ "
450,000 C. M.	1½ "
500,000 C. M.	1½ "
600,000 C. M.	1½ " or 2 "
700,000 C. M.	2 "
800,000 C. M.	2 "
900,000 C. M.	2 "
1,000,000 C. M.	2 " or 2½ "
1,500,000 C. M.	2½ "
1,700,000 C. M.	3 "
2,000,000 C. M.	3 "

TABLE III
Two Wires in One Conduit

Size Wire, B. & S. G.	Loricated Conduit, Unlined; D. B. Wire
No. 14	½ inch.
" 12	½ inch or ¾ "
" 10	¾ "
" 8	1 "
" 6	1 "
" 5	1 " or 1¼ "
" 4	1¼ "
" 3	1¼ "
" 2	1¼ " or 1½ "
" 1	1½ "
" 0	1½ "
" 00	1½ " or 2 "
" 000	2 "
" 0000	2 "
250,000 C. M.	2 " or 2½ "
300,000 C. M.	2½ "
350,000 C. M.	2½ "
400,000 C. M.	2½ " or 3 "
450,000 C. M.	3 "
500,000 C. M.	3 "
600,000 C. M.	3 "
700,000 C. M.	3 "

TABLE IV
Three Wires in One Conduit

Size Wire, B. & S. G.		Loricated Tube, Unlined; D. B. Wire
Outside	Center	
No. 14	No. 12	¾ inch
" 12	" 10	¾ "
" 10	" 8	1 "
" 8	" 6	1 "
" 6	" 4	1¼ "
" 5	" 2	1¼ "
" 4	" 1	1¼ inch or 1½ "
" 3	" 0	1½ "
" 2	" 2/0	1½ " or 2 "
" 1	" 3/0	2 "
" 0	" 4/0	2 "
" 2/0	250 M.	2 " or 2½ "
" 3/0	300 M.	2½ "
" 4/0	400 M.	2½ "
250 M.	450 M.	2½ " or 3 "
250 M.	500 M.	3 "
300 M.	600 M.	3 "
350 M.	700 M.	3 "
400 M.	800 M.	3 "
450 M.	900 M.	3 "

using these tables, for the reason that the sizes of conductors which may be safely installed in any run of conduit depend, of course, upon the length of and the number of bends in the run. The tables are based on average conditions where the run does not exceed 90 to 100 feet, without more than three or four bends, in the case of the smaller sizes of wires for a given size of conduit; and where the run does not exceed 40 to 50 feet, with not more than one or two bends, in the case of the larger sizes of wires, for the same sizes of conduit.

Unlined conduit can be bent without injury to the conduit, if the conduit is properly made and if proper means are used in making the bends. Care should be exercised to avoid flattening the tube as a result of making the bend over a sharp curve or angle.

In installing iron conduits, the conduits should cross sleepers or beams at right angles, so as to reduce the amount of cutting of the beams or sleepers to a minimum.

Where a number of conduits originate at a center of distribution, they should be run at right angles for a distance of two or three feet from the cut-out box, in order to obtain a symmetrical and workmanlike arrangement of the conduits, and so as to have them enter the cabinet in a neat manner. While it is usual to use red or white lead at the joints of conduits in order to make them water-tight, this is frequently unnecessary in the case of enameled conduit, as there is often sufficient enamel on the thread to make a water-tight joint.

When iron conduits are installed in ash concrete, in Keene cement, or, in general, where they are subject in any way to corrosive action, they should be coated with asphaltum or other similar protective paint to prevent such action.

While the cost of circuit work run in iron conduits is usually greater than any other method of wiring, it is the most permanent and durable, and is strongly recommended where the first cost is not the sole consideration. This method of wiring should always be used in fireproof buildings, and also in the better class of frame buildings. It is also to be recommended for exposed work where the work is liable to disturbance or mechanical damage.

Wires Run in Flexible Metal Conduit. This form of conduit, shown in Fig. 2, is described by the manufacturers as a conduit composed of "concave and convex metal strips wound spirally upon each other in such a manner as to interlock several concave surfaces and

present their convex surfaces, both exterior and interior, thereby securing a smooth and comparatively frictionless surface inside and out."

The field for the use of this form of conduit is rapidly increasing. Owing to its flexibility, conduit of this type can be used in numerous cases where the rigid conduit could not possibly be employed. Its use is to be recommended above all the other forms of wiring, except that installed in rigid conduits. For new fireproof buildings, it is not so durable as the rigid conduit, because not so water-tight; and it is very difficult, if not impossible, to obtain as workmanlike a conduit system with the flexible as with the rigid type of conduit. For completed or old frame buildings, however, the use of the flexible conduit is superior to all other forms of wiring.

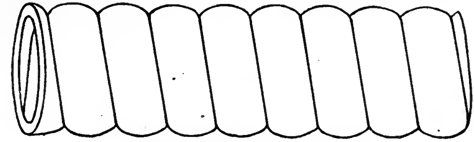

Fig. 2. Flexible Steel Conduit.
Courtesy of Sterling Electric Co., Troy, N. Y.

Table V gives the inside diameter of various sizes of flexible conduit, and the lengths of standard coils. inside diameter of this conduit is the same as that of the rigid conduit; and the table given for the maximum sizes of conductors which may be installed in the various sizes of conduits, may be used also for flexible steel conduits, except that a little more margin should be allowed for flexible steel conduits than for the rigid conduits, as the stiffness of the latter makes it possible to pull in slightly larger sized conductors.

TABLE V

Greenfield Flexible Steel Conduit

Inside Diameter	Approximate Feet in Coil
$\frac{5}{16}$ inch	200
$\frac{3}{8}$ "	200
$\frac{1}{2}$ "	100
$\frac{3}{4}$ "	50
1 "	50
$1\frac{1}{4}$ inches	50
$1\frac{1}{2}$ "	50
2 "	Random Lengths
$2\frac{1}{2}$ "	" "
3 "	" "

This conduit should, of course, be first installed without the conductors, in the same manner as the rigid conduit. Owing to the flexibility of this conduit, however, it is absolutely essential to fasten it securely at all elbows, bends, or offsets; for, if this is not done, considerable difficulty will be experienced in drawing the conductors in the conduit.

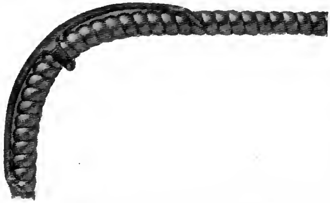

Fig. 3. Use of Elbow Clamp for Fastening Flexible Conduit in Place.

The rules governing the installation of this conduit are the same as those covering rigid conduits. Double-braided conductors are required, and the conduit should be grounded as required by the *Code Rules*. As already stated, the conduit should be securely fastened (in not less than three places) at all elbows; or else the special elbow clamp made for this purpose, shown in Fig. 3, should be used.

In order to cut flexible steel conduit properly, a fine hack saw should be employed. Outlet-boxes are required at all outlets, as well as bushing and wires to rigid conduit. Fig. 4 shows a coil of flexible steel conduit. Figs. 5, 6, and 7 show, respectively, an outlet box and cover, outlet plate, and bushing used for this conduit.

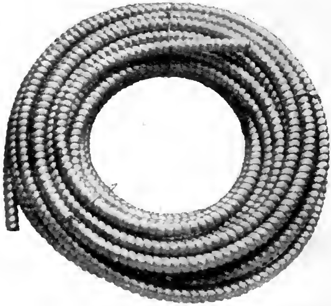

Fig. 4. A 100-Foot Coil of Flexible Steel Conduit.
Courtesy of Sprague Electric Co., New York, N.Y.

Armored Cable. There are many cases where it is impossible to install a conduit system. In such cases, probably the next best results may be obtained by the use of *steel armored cable.* The rules governing the installation of armored cable are given in the *National Electric Code,* under Section 24-A, and Section 48; also in 24–S. This cable is shown in Fig. 8.

Steel armored cable is made by winding formed steel strips over the insulated conductors. The steel strips are similar to those used

for the steel conduit. Care is taken in forming the cable, to avoid crushing or abraiding the insulation on the conductors as the steel

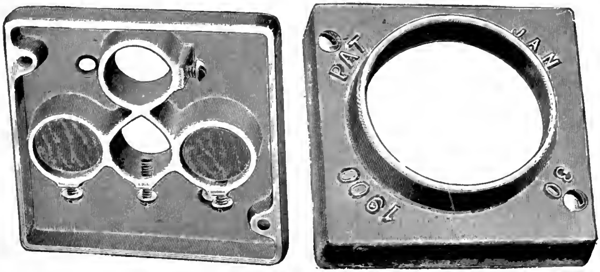

Fig. 5. Outlet Box for Flexible Steel Conduit.

strips are fed and formed over the same. In the process of manufacture, the spools of steel ribbon are of irregular length, and when a

Fig. 6. Outlet Plate for Flexible Steel Conduit.

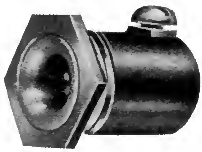

Fig. 7. Outlet Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

spool is empty, the machine is stopped, and the ribbon is started on the next spool, the process being continued. There is no reason why

Fig. 8. Flexible Armored Cable. Twin Conductors.
Courtesy of Sprague Electric Co., New York, N. Y.

the conduit cables could not be made of any length; but their actual lengths as made are determined by convenience in handling. Armored

cable is made in *single conductors* from No. 1 to No. 10 B. & S. G.; in *twin conductors*, from No. 6 to No. 14 B. & S. G.; and *three-conductor* cable, from No. 10 to No. 14 B. & S. G. Table VI gives various data relating to armored conductors:

TABLE VI

Armored Conductors—Types, Dimensions, Etc.

Size B. & S. Gauge	Type and Number of Conductors	Outside Diameter (Inches)
No. 14	BX twin conductor	.63
" 12	" " "	.685
" 10	" " "	.725
" 8	" " "	.875
" 6	" " "	1.3125
" 14	BM twin conductor (for marine work—ship wiring)	.725
" 12	" " "	.725
" 10	" " "	.73
" 14	BX3 three conductor	.71
" 12	" " "	.725
" 10	" " "	.73
" 14	BXL twin conductor, leaded	.725
" 12	" " " "	.725
" 10	" " " "	.87
" 14	BXL3 three conductor, leaded	.90
" 12	" " " "	.90
" 10	" " " "	.94
" 10	Type D single conductor, stranded	.550
" 8	" " " " "	.550
" 6	" " " " "	.575
" 4	" " " " "	.700
" 2	" " " " "	.900
" 1	" " " " "	.965
" 10	Type DL single conductor, stranded, leaded	.625
" 8	" " " " " "	.710
" 6	" " " " " "	.700
" 4	" " " " " "	.760
" 2	" " " " " "	.920
" 1	" " " " " "	.910
	Steel Armored Flexible Cord	
" 18	Type E twin conductor	.40
" 16	" " " "	.40
" 14	" " " "	.47
" 18	Type EM twin conductor, re-inforced	.575
" 16	" " " " "	.585
" 14	" " " " "	.595

In Table VI, Types D (single), BX (twin), and BX3 (3 conduc-

tors) are armored cable adapted for ordinary indoor work. Type BM (twin conductors) is adapted for marine wiring. Types DL (single), BXL (twin), and BXL 3 (3 conductors) have the conductors lead-encased, with the steel armor outside, and are especially adapted for damp places, such as breweries, stables, and similar places.

Type E is used for flexible-cord pendants, and is suitable for factories, mills, show windows, and other similar places. Type EM is the same as Type E; but the flexible cord is reinforced, and is suitable for marine work, for use in damp places, and in all cases where it will be subject to very rough handling.

While this form of wiring has not the advantage of the conduit system—namely, that the wires can be withdrawn and new wires inserted without disturbing the building in any way whatever—yet it has many of the advantages of the flexible steel conduit, and it has some additional advantages of its own. For example, in a building already erected, this cable can be fished between the floors and in the partition walls, where it would be impossible to install either rigid conduit or flexible steel conduit without disturbing the floors or walls to an extent that would be objectionable.

Armored conductors should be continuous from outlet to outlet, without being spliced and installed on the loop system. Outlet boxes should be installed at all outlets, although, where this is impossible, outlet plates may be used under certain conditions. Clamps should be provided at all outlets, switch-boxes, junction-boxes, etc., to hold the cable in place, and also to serve as a means of grounding the steel sheathing.

Armored cable is less expensive than the rigid conduit or the flexible steel conduit, but more expensive than cleat wiring or knob and tube wiring, and is strongly recommended in preference to the latter.

WIRES RUN IN MOULDING

Moulding is very extensively used for electric circuit work, in extending circuits in buildings which have already been wired, and also in wiring buildings which were not provided with electric circuit work at the time of their erection. The reason for the popularity of moulding is that it furnishes a convenient and fairly good-looking runway for the wires, and protects them from mechanical injury.

It seems almost unwise to place conductors carrying electric current, in wood casing; but this method is still permitted by the *National Electric Code,* although it is not allowed in damp places or in places where there is liability to dampness, such as on brick walls, in cellars, etc.

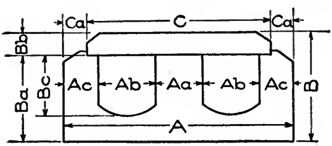

Fig. 9. Two-Wire Wood Moulding.

The dangers from the use of moulding are that if the wood becomes soaked with water, there will be a liability to leakage of current between the conductors run in the grooves of the moulding, and to fire being thereby started, which may not be immediately discovered. Furthermore, if the conductors are overloaded, and consequently overheated, the wood is likely to become charred and finally ignited. Moreover, the moulding itself is always a temptation as affording a good "round strip" in which to drive nails, hooks, etc. However, the convenience and popularity of moulding cannot be denied; and until some better substitute is found, or until its use is forbidden by the *Rules,* it will continue to be used to a very great extent for running circuits outside of the walls and on the ceilings of existing buildings. Figs. 9, 10, 11, and 12 show two- and three-wire moulding respectively; and Table VII gives complete data as to sizes of the moulding required for various sizes of conductors.

While the *Rules* recommend the use of hardwood moulding, as a matter of fact probably 90 per cent of the moulding used is of whitewood or other similar cheap, soft wood. Georgia pine or oak ordinarily

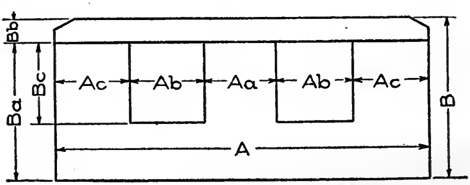

Fig. 10. Two-Wire Wood Moulding.

costs about twice as much as the soft wood. In designing moulding work, if appearance is of importance, the moulding circuits should be laid out so as to afford a symmetrical and complete design. For

example, if an outlet is to be located in the center of the ceiling, the moulding should be continued from wall to wall, the portion beyond the outlet, of course, having no conductors inside of the moulding. If four outlets are to be placed on the ceiling, the rectangle of moulding should be completed on the fourth side, although, of course, no con-

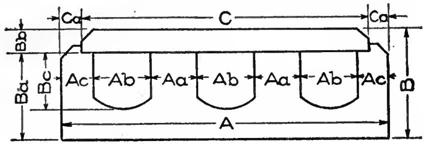

Fig. 11. Three-Wire Wood Moulding.

ductors need be placed in this portion of the moulding. Doing this increases the cost but little and adds greatly to the appearance.

Moulding is frequently used in combination with other methods of wiring, including armored cable, flexible steel tubing, and fibrous tubing. In many instances, it is possible to fish tubing between beams or studs running in a certain direction; but when the conductors are to run in another direction or at right angles to the beams or studs, exposed work is necessary. In such cases, a junction-box or outlet-box must be placed at the point of connection between the moulding and the armored cable or steel tubing.

Where circuits are run in moulding, and pass through the floor, additional protection must be provided, as required by the *Code Rules*,

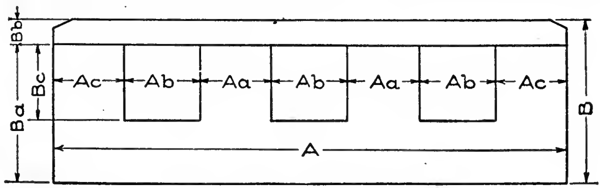

Fig. 12. Three-Wire Wood Moulding.

to protect the moulding. As a rule, it is better to use conduit for all portions of moulding within six feet of the floor, so as to avoid the possibility of injury to the circuits. Where a combination of iron conduit or flexible steel tubing is used with moulding, it is well to use double-braided conductors throughout, because, although only single-

TABLE VII

Sizes of Mouldings Required for Various Sizes of Conductors

FIG. No.	TYPE OF MOULDING	NUMBER OF WIRES	MAXIMUM SIZE OF WIRE B. AND S. GAUGE		DIMENSIONS IN INCHES									
			SOLID	STRANDED	A	Aa	Ab	Ac	B	Ba	Bb	Bc	C	Ca
9	A-2	2	12	14	$1\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{27}{32}$	$\frac{5}{8}$	$\frac{7}{32}$	$\frac{1}{4}$	$1\frac{1}{8}$	$\frac{3}{16}$
9	A-4	2	8	10	$1\frac{11}{16}$	$\frac{1}{2}$	$\frac{5}{16}$	$\frac{9}{32}$	$\frac{29}{32}$	$\frac{11}{16}$	$\frac{7}{32}$	$\frac{5}{16}$	$1\frac{5}{16}$	$\frac{3}{16}$
9	A-6	2	4	5	2	$\frac{1}{2}$	$\frac{7}{16}$	$\frac{5}{16}$	$1\frac{1}{16}$	$\frac{13}{16}$	$\frac{1}{4}$	$\frac{7}{16}$	$1\frac{9}{16}$	$\frac{7}{32}$
9	A-8	2	1	2	$2\frac{3}{8}$	$\frac{1}{2}$	$\frac{9}{16}$	$\frac{3}{8}$	$1\frac{3}{16}$	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{9}{16}$	$1\frac{13}{16}$	$\frac{9}{32}$
9	A-9	2	—	3/0	3	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{16}$	$1\frac{13}{32}$	$1\frac{1}{8}$	$\frac{9}{32}$	$\frac{3}{4}$	$2\frac{7}{16}$	$\frac{9}{32}$
10	A-10	2	—	250,000 C.M.	$3\frac{15}{16}$	$\frac{11}{16}$	$\frac{7}{8}$	$\frac{3}{4}$	$1\frac{11}{16}$	$1\frac{3}{8}$	$\frac{5}{16}$	$\frac{7}{8}$	—	—
10	A-11	2	—	400,000 C.M.	$4\frac{7}{8}$	$\frac{15}{16}$	1	$\frac{31}{32}$	$2\frac{3}{16}$	$1\frac{7}{8}$	$\frac{5}{16}$	1	—	—
11	B-2	3	12	14	$2\frac{3}{16}$	$\frac{7}{16}$	$\frac{1}{4}$	$\frac{9}{32}$	$\frac{27}{32}$	$\frac{5}{8}$	$\frac{7}{32}$	$\frac{1}{4}$	$1\frac{13}{16}$	$\frac{3}{16}$
11	B-4	3	8	10	$2\frac{1}{2}$	$\frac{15}{32}$	$\frac{5}{16}$	$\frac{5}{16}$	$\frac{29}{32}$	$\frac{11}{16}$	$\frac{7}{32}$	$\frac{5}{16}$	$2\frac{1}{8}$	$\frac{3}{16}$
11	B-6	3	4	5	$2\frac{7}{8}$	$\frac{13}{32}$	$\frac{7}{16}$	$\frac{3}{8}$	$1\frac{1}{16}$	$\frac{13}{16}$	$\frac{1}{4}$	$\frac{7}{16}$	$2\frac{3}{8}$	$\frac{1}{4}$
11	B-8	3	1	2	$3\frac{5}{8}$	$\frac{19}{32}$	$\frac{9}{16}$	$\frac{3}{8}$	$1\frac{3}{16}$	$\frac{15}{16}$	$\frac{1}{4}$	$\frac{9}{16}$	$3\frac{1}{16}$	$\frac{9}{32}$
11	B-9	3	—	3/0	$4\frac{5}{16}$	$\frac{9}{16}$	$\frac{3}{4}$	$\frac{15}{32}$	$1\frac{13}{32}$	$1\frac{1}{8}$	$\frac{9}{32}$	$\frac{3}{4}$	$3\frac{3}{4}$	$\frac{9}{32}$
12	B-10	3	—	250,000 C.M.	$5\frac{1}{2}$	$\frac{23}{32}$	$\frac{7}{8}$	$\frac{23}{32}$	$1\frac{11}{16}$	$1\frac{3}{8}$	$\frac{5}{16}$	$\frac{7}{8}$	—	—
12	B-11	3	—	400,000 C.M.	$6\frac{3}{4}$	$\frac{15}{16}$	1	$\frac{15}{16}$	$2\frac{3}{16}$	$1\frac{7}{8}$	$\frac{5}{16}$	1	—	—

braided conductors are required with moulding, double-braided conductors are required with unlined conduit, and if double-braided conductors were not used throughout, it would be necessary to make a joint at the outlet-box where the moulding stopped and the conduit work commenced. Where the conductors pass through floors, in moulding work, and where iron conduit is used, the inspection authorities, in order to protect the wire, usually require that a fibrous tubing be used as additional protection for the conductors inside of the iron pipe, although, if double-braided wire is used, this will not usually be required. Fig. 13 shows a fuseless cord rosette for use with moulding work. Fig. 14 shows a device for making a *tap* in moulding wiring.

Moulding work, under ordinary conditions, costs about one-half as much as circuit run in rigid conduit, and about 75 per cent, under

ordinary conditions, of the cost of armored cable. Where the latter method of wiring or the conduit system can be employed, one or the other of these two methods should be used in preference to moulding,

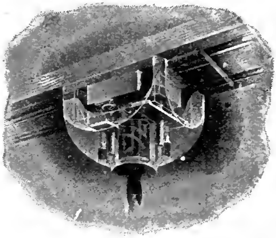

Fig. 13 Fuseless Cord Rosette.
Courtesy of Crouse-Hinds Co., Syracuse, N. Y.

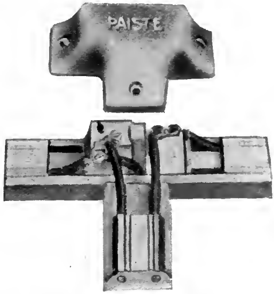

Fig. 14. Device for Making "Tap" in Moulding.
Courtesy of H. T. Paiste Co., Philadelphia, Pa.

as the work is not only more substantial, but also safer. Various forms of metal moulding have been introduced, but up to the present time have not met with the success which they deserve.

CONCEALED KNOB AND TUBE WIRING

This method of wiring is still allowed by the *National Electric Code,* although many vigorous attempts have been made to have it abolished. Each of these attempts has met with the strongest opposition from contractors and central stations, particularly in small towns and villages, the argument for this method being, that it is the cheapest method of wiring, and that if it were forbidden, many places which are wired according to this method would not be wired at all, and the use of electricity would therefore be much restricted, if not entirely done away with, in such communities. This argument, however, is only a temporary makeshift obstruction in the way of inevitable progress, and in a few years, undoubtedly, the concealed knob and tube method will be forbidden by the *National Electric Code.*

The cost of wiring according to this method is about one-third of the cost of circuits run in rigid conduit, and about one-half of the cost of circuits run in armored cable. The latter method of wiring

is rapidly replacing knob and tube wiring, and justly so, wherever the additional price for the latter method of wiring can be obtained. As the name indicates, this method of wiring employs *porcelain knobs*

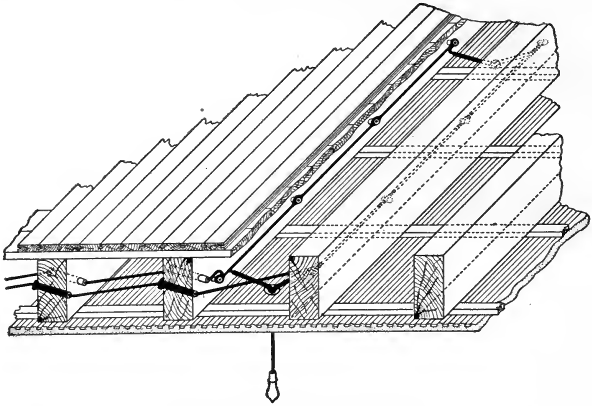

Fig. 15. Knob and Tube Wiring.

and tubes, the circuit work being run *concealed* between the floor beams and studs of a frame building. The knobs are used when the circuits run parallel to the floor beams; and the porcelain tubes are used when the circuits are run at right angles to the floor beams.

Fig. 15 shows an example of knob and tube wiring. In concealed knob and tube wiring, the wires must be separated at least ten inches from one another, and at least one inch from the surface wired over, that is, from the beams, flooring, etc., to which the insulator is fastened. Fig. 16 shows a good type of porcelain knob for this class of wiring. For knob and tube wiring, it will be noted that, owing to the fact that the wiring is concealed, the conductors must be kept further apart than in the case of exposed or open wiring on insulators, where, except in damp places, the wires may be run on cleats or on insulators only one-half inch from the surface wired over.

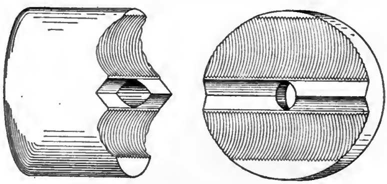

Fig. 16. Porcelain Knob.

Fibrous Tubing. Fibrous tubing is frequently used with knob and tube wiring, and the regulations governing its use are given in Rule 24, Section S, of the *National Electric Code.* This tubing, as stated in this *Rule,* may be used where it is impossible and impracticable to employ knobs and tubes, provided the difference in potential between the wires is not over 300 volts, and if the wires are not sub-

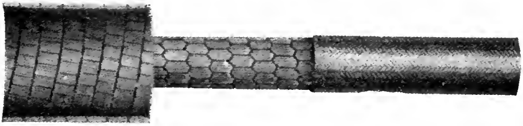

Fig. 17. Flexible Tubing, "Flexduct" Type.
Courtesy of National Metal Molding Co., Pittsburg, Pa.

ject to moisture. The cost of wiring in flexible fibrous tubing is approximately about the same as the cost of knob and tube wiring. Duplex conductors, or two wires together are not allowed in fibrous tubing.

Fibrous tubing is required at all outlets where conduit or armored cable is not used (as in knob and tube wiring); and, as required by the *Rules,* it must extend back from the last porcelain support to one inch beyond the outlet. Fig. 17 shows one make of fibrous tubing.

Table VIII gives the maximum sizes of conductors (double-braided) which may be installed in fibrous conduit.

TABLE VIII

Sizes of Conductors in Fibrous Conduit

Outside Diameter	Inside Diameter	One Wire in Tube
$\frac{17}{32}$ inch	$\frac{1}{4}$ inch	No. 12
$\frac{21}{32}$ "	$\frac{3}{8}$ "	" 8
$\frac{25}{32}$ "	$\frac{1}{2}$ "	" 6
$\frac{15}{16}$ "	$\frac{5}{8}$ "	" 1
$1\frac{3}{32}$ "	$\frac{3}{4}$ "	" 2/0
$1\frac{5}{16}$ "	1 "	250,000 C. M.
$1\frac{9}{16}$ "	$1\frac{1}{4}$ "	400,000 C. M.
$1\frac{13}{16}$ "	$1\frac{1}{2}$ "	750,000 C. M.
$2\frac{1}{8}$ "	$1\frac{3}{4}$ "	1,000,000 C. M.
$2\frac{3}{8}$ "	2 "	1,500,000 C. M.
$2\frac{5}{8}$ "	$2\frac{1}{4}$ "	2,000,000 C. M.

WIRES RUN EXPOSED ON INSULATORS

This method of wiring has the advantages of cheapness, durability, and accessibility.

Cheapness. The relative cost of this method of wiring as compared with that of the concealed conduit system, is about fifty per cent of the latter if rubber-covered conductors are used, and about forty per cent of the latter if weatherproof slow-burning conductors are used. As the *Rules* of the Fire Underwriters allow the use of weatherproof slow-burning conductors in dry places, considerable saving may be effected by this method of wiring, provided there is no objection to it

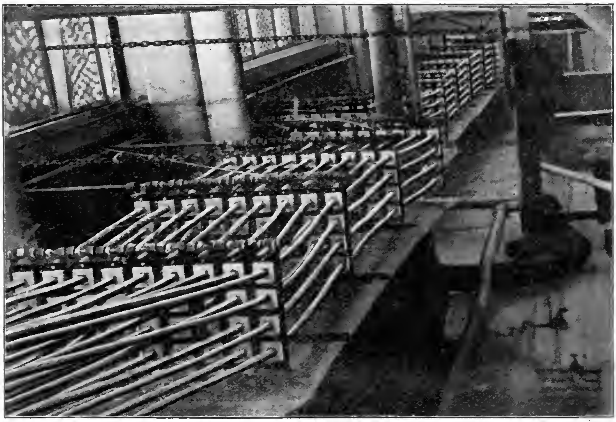

Fig. 18. Large Feeders Run Exposed on Insulators.

from the standpoint of appearance, and also provided that it is not liable to mechanical injury or disarrangement.

Durability. It is a well-known fact that rubber insulation has a relatively short life. Inasmuch as in this method of wiring, the insulation does not depend upon the insulation of the conductors, but on the insulators themselves, which are of glass or porcelain, this system is much more desirable than any of the other methods. Of course, if the conductors are mechanically injured, or the insulators broken, the insulation of the system is reduced; but there is no gradual deterioration as there is in the case of other methods of wiring, where

rubber is depended upon for insulation. This is especially true in hot places, particularly where the temperature is 120° F. or above. For such cases, the weatherproof slow-burning conductors on porcelain or glass insulators are especially recommended.

Accessibility. The conductors being run exposed, they may be readily repaired or removed, or connections may be made to the same.

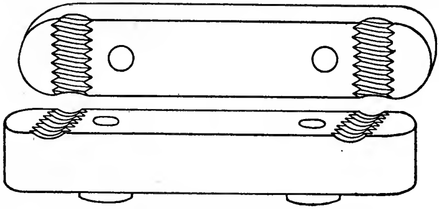

Fig. 19. Two-Wire Cleat.

This method of wiring is especially recommended for mills, factories, and for large or long feeder conductors. Fig. 18 shows examples of exposed large feeder conductors, installed in the New York Life Insurance Building, New York City. For small conductors, up to say No. 6 B. & S. Gauge each, porcelain cleats may be used to support one, two, or three conductors, provided the distance between the conductors is at least $2\frac{1}{2}$ inches in a two-wire system, and $2\frac{1}{2}$ inches between the two outside conductors in a three-wire system where the potential between the outside conductors is not over 300 volts. The cleat must hold the wire at least one-half inch from the surface to which the cleat is fastened; and in damp places the wire must be held at least one inch from the surface wired over. For larger conductors,

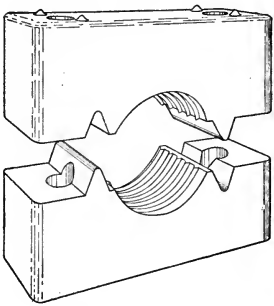

Fig. 20. One-Wire Cleat.

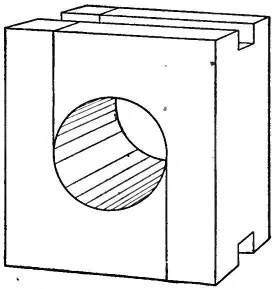

Fig. 21. Porcelain Insulator for Large Conductors.

from No. 6 to No. 4 / 0 B. & S. Gauge, it is usual to use single porcelain cleats or knobs. Figs. 19 and 20 show a good form of two-wire

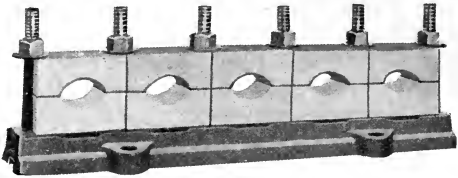

Fig. 22. Iron Rack and Insulators for Large Conductors.
Courtesy of General Electric Co., Schenectady, N. Y.

cleat and single-wire cleat, respectively.

For large feeder or main conductors from No. 4 / 0 B. & S. Gauge upward, a more substantial form of porcelain insulator should be used, such as shown in Fig. 21. These insulators are held in iron racks or angle-iron frames, of which two forms are shown in Figs. 22 and 23. The latter form of rack is particularly desirable for heavy conductors and where a number of conductors are run together. In this form of rack, any length of conductor can be removed without disturbing the other conductors.

As a rule, the porcelain insulators should be placed not more than $4\frac{1}{2}$ feet apart; and if the wires are liable to be disturbed, the distance between supports should be shortened, particularly for small conductors. If the beams are so far apart that supports cannot be obtained every $4\frac{1}{2}$ feet, it is necessary to provide a running board as shown in Fig. 24, to which the porcelain cleats and knobs can be fastened. Figs. 25 and 26 show two methods of supporting small conductors. For conductors of No. 8 B. & S.

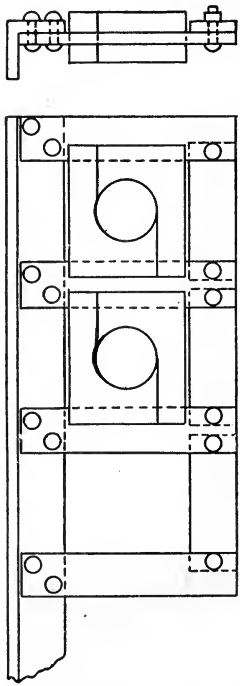

Fig. 23. Elevation and Plan of Insulators Held in Angle-Iron Frames.

Gauge, or over, it is not necessary to break around the beams, provided they are not liable to be disturbed; but the supports may be placed on each beam.

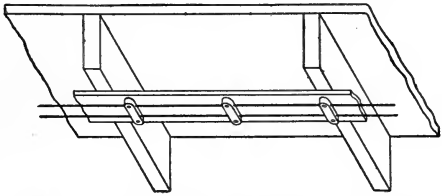

Fig. 24. Insulators Mounted on Running-Board across Wide-Spaced Beams.

Where the distance between the supports, however, is greater than $4\frac{1}{2}$ feet, it is usually necessary to provide intermediate supports, as shown in Fig. 27, or else to provide a running-board. Another method which may be used, where beams are further than $4\frac{1}{2}$ feet apart, is to

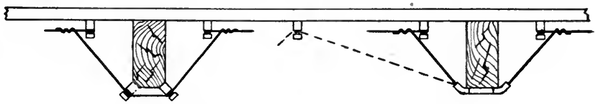

Fig. 25. Method of Supporting Small Conductors.

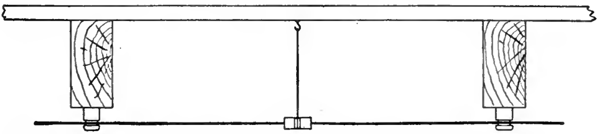

Fig. 27. Intermediate Support for Conductor between Wide-Spaced Beams.

run a main along the wall at right angles to the beams, and to have the individual circuits run between and parallel to the beams.

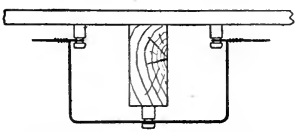

Fig. 26. Method of Supporting a Small Conductor.

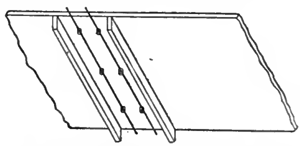

Fig. 28. Conductors Protected by Wooden Guard Strips on Low Ceiling.

In low-ceiling rooms, where the conductors are liable to injury, it is usually required that a wooden guard strip be placed on each side of the conductors, as shown in Fig. 28.

Where the conductors pass through partitions or walls, they must

be protected by porcelain tubes, or, if the conductors be of rubber, by means of fibrous tubing placed inside of iron conduits.

All conductors on the walls for a height of not less than six feet from the ground, either should be boxed in, or, if they be rubber-covered, should (preferably) be run in iron conduits; and in conductors having single braid only, additional protection should be provided by means of flexible tubing placed inside of the iron conduit.

Where conductors cross each other, or where they cross iron pipes, they should be protected by means of porcelain tubes fastened with tape or in some other substantial manner that will prevent the tubes from slipping out of place.

TWO-WIRE AND THREE-WIRE SYSTEMS

As both the two-wire and the three-wire system are extensively used in electric wiring, it will be well to give some consideration to the advantages and disadvantages of each system, and to explain them somewhat in detail.

Relative Advantages. The choice of either a two-wire or a three-wire system depends largely upon the source of supply. If, for example, the source of supply will always probably be a 120-volt, two-wire system, there would be no object in installing a three-wire system for the wiring. If, on the other hand, the source of supply is a 120-240-volt system, the wiring should, of course, be made three-wire. Furthermore, if at the outset the supply were two-wire, but with a possibility of a three-wire system being provided later, it would be well to adapt the electric wiring for the three-wire system, making the neutral conductor twice as large as either of the outside conductors, and combining the two outside conductors to make a single conductor until such time as the three-wire service is installed. Of course, there would be no saving of copper in this last-mentioned three-wire system, and in fact it would be slightly more expensive than a two-wire system, as will be shortly explained.

The object of the three-wire system is to reduce the amount of copper—and consequently the cost of wiring—necessary to transmit a given amount of electric power. As a rule, the proposition is usually one of lighting and not of power, for the reason that by means of the three-wire system we are able to increase the potential at which the current is transmitted, and at the same time to take advantage of the

greater efficiency of the lower voltage lamp. If current for power (motors, etc.) only were to be transmitted, it would be a simple matter to wind the motors, etc., for a higher voltage, and thereby reduce the weight of copper. If, however, we increase the voltage of lamps, we find that they are not so efficient, nor is their life so long. With the standard carbon lamp, it has been found that the 240-volt lamp, with the same life, requires about 10 to 12 per cent more current than the corresponding 120-volt lamp. Furthermore, in the case of the more efficient lamps recently introduced (such as the Tantalum lamp, Tungsten lamp, etc.), it has been found impracticable, if not impossible, to make them for pressures above 125 volts. For this reason the three-wire system is employed, for by this method we can use 240 volts across the outside conductors, and by the use of a neutral conductor obtain 120 volts between the neutral and the outside conductor, and thereby be enabled to use 120-volt lamps. Furthermore, if a 240-volt lamp should ever be placed on the market that was as economical as the lower voltage lamp, the result would be that the 240-480-volt system would be introduced, and 240-volt lamps used. As a matter of fact, this has been tried in several cities—and particularly in Providence, Rhode Island. As a rule, however, the 120-volt lamp has been found so much more satisfactory as regards life, efficiency, etc., that it is nearly always employed.

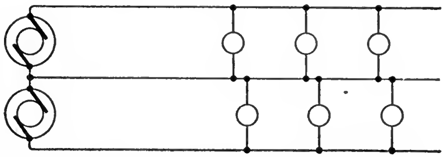

Fig. 29. Three-Wire System, with Neutral Conductor between the Two Outside Conductors.

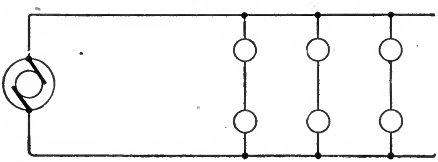

Fig. 30. Lamps Arranged in Pairs in Series, Dispensing with Necessity for Third or Neutral Conductor.

The two-wire system is so extremely simple that no explanation whatever is required concerning it.

The three-wire system, however, is somewhat confusing, and will now be considered.

Details of Three-Wire System. The three-wire system may be considered as a two-wire system with a third or neutral conductor placed between the two outside conductors, as shown in Fig. 29. This neutral conductor would not be required if we could always have the lamps arranged in pairs, as shown in Fig. 30. In this case, the two lamps would burn in series, and we could transmit the current at double the usual voltage, and thereby supply twice the number of lamps with one-quarter the weight of copper, allowing the same loss in pressure in the lamps. The reason for this is, that, having the lamps arranged in series of pairs, we reduce the current to one-half, and, as the pressure at which the current is transmitted is doubled, we can again reduce the copper one-half without increasing the loss in lamps. We therefore see that we have a double saving, as the current is reduced one-half, which reduces the weight of copper one-half, and we can again reduce the copper one-half by doubling the loss in volts without increasing the percentage loss. For example, if in one case we had a straight two-wire system transmitting current to 100 lamps at a potential of 100 volts, and this system were replaced by one in which the lamps were placed in series of pairs, as shown in Fig. 30, and the potential increased to 200 volts—100 lamps still being used—we should find, in the latter case, that we were carrying current really for only 50 lamps, as we would require only the same amount of current for two lamps now that we required for one lamp before. Furthermore, as the potential would now be 200 instead of 100 volts, we could allow twice as much loss as in the first case, because the loss would now be figured as a percentage of 200 volts instead of a percentage of 100 volts. From this, it will readily be seen that in the second case mentioned, we would require only one-quarter the weight of copper that would be required in the first case.

It will readily be seen, however, that a system such as that outlined in the second scheme having two lamps, would be impracticable for ordinary purposes, for the reason that it would always require the lamps to be burned in pairs. Now, it is for this very reason that the third or neutral conductor is required; and, if this conductor be added, it will no longer be necessary to burn the lamps in pairs. This, then, is the object of the three-wire system—to enable us to reduce the amount of copper required for transmitting current, without increasing the electric pressure employed for the lamps.

With regard to the size of the neutral conductor, one important point must be borne in mind; and that is, that the *Rules of the National Electric Code* require the neutral conductor in all interior wiring to be made at least as large as either of the two outside conductors. The reasons for this from a fire standpoint are obvious, because, if for any reason either of the outside conductors became disconnected, the neutral wire might be required to carry the same current as the outside conductors, and therefore it should be of the same capacity. Of course, the chances of such an event happening are slight; but, as the fire hazard is all-important, this rule must be complied with for interior wiring or in all cases where there would be a probability of fire. For outside or underground work, however, where the fire hazard would be relatively unimportant, the neutral conductor might be reduced in size; and, as a matter of fact, it is made smaller than the outside conductors.

The three-wire system is sometimes installed where it is desired to use the system as a two-wire, 125-volt system, or to have it arranged so that it may be used at any time also as a three-wire, 125-250-volt system. Of course, in order to do this, it is necessary to make the neutral conductor equal to the combined capacity of the outside conductors, the latter being then connected together to form one conductor, the neutral being the return conductor. This system is not recommended except in such instances, for example, as where an isolated plant of 125 volts is installed, and where there is a possibility of changing over at some future time to the three-wire, 125-250-volt system. In such a case as this, however, it would be better, where possible, to design the isolated plant for a three-wire, 125-250-volt system originally, and then to make the neutral conductor the same size as each of the two outside conductors.

The weight of copper required in a three-wire system where the neutral conductor is the same size as either of the two outside conductors, is $\frac{3}{8}$ of that required for a corresponding two-wire system using the same voltage of lamps.* It is obvious that this is true, because,

*Note.—If, in the two-wire system, we represent the weight of each of the two conductors by $\frac{1}{2}$, the weight of each of the outside conductors in a three-wire system would be represented by $\frac{1}{8}$, and if we had three conductors of the same size, we woud have $\frac{1}{8}+\frac{1}{8}+\frac{1}{8}=\frac{3}{8}$ of the weight of copper required in a three-wire system, which would be required in a corresponding two-wire system having the same percentage of loss and using the same voltage of lamps.

If the neutral conductor were made $\frac{1}{2}$ of the size of each of the outside conductors, as is sometimes done in underground work, the total weight of copper required would be $\frac{1}{8}+\frac{1}{8}+\frac{1}{16}=\frac{5}{16}$ of that required in the corresponding two-wire system.

as the discussion proved concerning the arrangement shown in Fig. 30, where the lamps were placed in series of pairs, we found that the weight of copper for the two conductors was one-quarter the weight of the regular two-wire system. It is then of course true, that, if we had another conductor of the same size as each of the outside conductors, we increase theweight of copper one-half, or one-quarter plus one-half of one-quarter—that is, three-eighths.

In the three-wire system frequently used in isolated plants in which the two outside conductors are joined together and the neutral conductor made equal to their combined capacity, there is no saving of copper, for the reason that the same voltage of transmission is used, and, consequently, we have neither reduced the current nor increased the potential. Furthermore, though the weight of copper is the same, it is now divided into three conductors, instead of two, and naturally it costs relatively more to insulate and manufacture three conductors than to insulate and manufacture two conductors having the same total weight of copper. As a matter of fact, the three-wire system, having the neutral conductor equal to the combined capacity of the two outside ones, the latter being joined together, is about 8 to 10 per cent more expensive than the corresponding straight two-wire system.

In interior wiring, as a rule, where the three-wire system is used for the mains and feeders, the two-wire system is nearly always employed for the branch circuits. Of course, the two-wire branch circuits are then balanced on each side of the three-wire system, so as to obtain as far as possible at all times an equal balance on the two sides of the system. This is done so as to have the neutral conductor carry as little current as possible. From what has already been said, it is obvious that in case there is a perfect balance, the lamps are virtually in series of pairs, and the neutral conductor does not carry any current. Where there is an unbalanced condition, the neutral conductor carries the difference between the current on one side and the current on the other side of the system. For example, if we had five lamps on one side of the system and ten lamps on the other, the neutral conductor would carry the current corresponding to five lamps.

In calculating the three-wire system, the neutral conductor is disregarded, the outer wires being treated as a two-wire circuit, and the calculation is for one-half the total number of lamps, the per-

centage of loss being based on the potential across the two outside conductors.

The three-wire system is very generally employed in alternating-current secondary wiring, as nearly all transformers are built with three-wire connections.

While unbalancing will not affect the total loss in the outside conductors, yet it does affect the loss in the lamps, for the reason that the system is usually calculated on the basis of a perfect balance, and the loss is divided equally between the two lamps (the latter being considered in series of pairs). If, however, there is unbalancing to a great degree, the loss in lamps will be increased; and if the entire load is thrown over on one side, the loss in the lamps will be doubled on the remaining side, because the total loss in voltage will now occur in these lamps, whereas, in the case of perfect balance, it would be equally divided between the two groups of lamps.

CALCULATION OF SIZES OF CONDUCTORS

The formula for calculating the sizes of conductors for direct currents, where the length, load, and loss in volts are given, is as follows:

The size of conductor (in circular mils) is equal to the current *multiplied by* the distance (one way), *multiplied by* 21.6, *divided by* the loss in volts; or,

$$CM = \frac{C \times D \times 21.6}{V} \quad \ldots\ldots\ldots\ldots\ldots (1)$$

in which C = Current, in amperes;
D = Distance or length of the circuit (one way, in feet);
V = Loss in volts between the beginning and end of the circuit.

The constant (21.6) of this formula is derived from the resistance of a mil foot of wire of 98 per cent conductivity at 25° Centigrade or 77° Fahrenheit. The resistance of a conductor of one mil diameter and one foot long, is 10.8 at the temperature and conductivity named. We multiply this figure (10.8) by 2, as the length of a circuit is usually given as the distance one way, and in order to obtain the resistance of both conductors in a two-wire circuit, we must multiply by 2. The formula as above given, therefore, is for a two-wire circuit; and in calculating the size of conductors in a three-wire system, the calculation should be made on a two-wire basis, as explained hereinafter.

Formula **1** can be transformed so as to obtain the loss in a given circuit, or the current which may be carried a given distance with a stated loss, or to obtain the distance when the other factors are given, in the following manner:

Formula for Calculating Loss in Circuit when Size, Current, and Distance are Given

$$V = \frac{C \times D \times 21.6}{CM} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Formula for Calculating Current which may be Carried by a Given Circuit of Specified Length, and with a Specified Loss

$$C = \frac{CM \times V}{D \times 21.6} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

Formula for Calculating Length of Circuit when Size, Loss, and Current to be Carried are Given

$$D = \frac{CM \times V}{C \times 21.6} \quad \ldots\ldots\ldots\ldots\ldots (4)$$

Formulæ are frequently given for calculating sizes of conductors, etc., where the load, instead of being given in amperes, is stated in lamps or in horse-power. It is usually advisable, however, to reduce the load to amperes, as the efficiency of lamps and motors is a variable quantity, and the current varies correspondingly.

It is sometimes convenient, however, to make the calculation in terms of watts. It will readily be seen that we can obtain a formula expressed in watts from Formula **1**. To do this, it is advisable to express the loss in volts in percentage, instead of actual volts lost. It must be remembered that, in the above formulæ, V represents the volts lost in the circuit, or, in other words, the difference in potential between the beginning and the end of the circuit, and is not the applied E. M. F. The loss in percentage, in any circuit, is equal to the actual loss expressed in volts, *divided by* the line voltage, *multiplied by* 100; or,

$$P = \frac{V}{E} \times 100.$$

From this equation, we have:

$$V = \frac{P\,E}{100}.$$

If, for example, the calculation is to be made on a loss of 5 per cent, with an applied voltage of 250, using this last equation, we would have:

$$V = \frac{5 \times 250}{100} = 12.5 \text{ volts.}$$

Substituting the equation $V = \frac{P\,E}{100}$ in Formula **1**, we have:

$$C\,M = \frac{C \times D \times 21.6}{\frac{P\,E}{100}}$$

$$= \frac{C \times D \times 21.6 \times 100}{P\,E}$$

$$= \frac{C \times D \times 2{,}160}{P\,E}.$$

This equation, it should be remembered, is expressed in terms of applied voltage. Now, since the power in watts is equal to the applied voltage *multiplied by* the current ($W = EC$), it follows that

$$C = \frac{W}{E}.$$

By substituting this value of C in the equation given above $\left(C\,M = \frac{C \times D \times 2{,}160}{P\,E}\right)$, the formula is expressed in terms of watts instead of current, thus:

$$CM = \frac{W \times D \times 2{,}160}{E\,P\,E}, \qquad \textbf{(5)}$$

in which W = Power in watts transmitted;
D = Length of the circuit (one way)—that is, the length of one conductor;
P = Figure representing the percentage loss;
E* = Applied voltage.

All the above formulæ are for calculations of two-wire circuits. In making calculations for three-wire circuits, it is usual to make the calculation on the basis of the two outside conductors; and in three wire calculations, the above formulæ can be used with a slight modification, as will be shown.

In a three-wire circuit, it is usually assumed in making the calculation, that the load is equally balanced on the two sides of the neutral conductor; and, as the potential across the outside conductors is double that of the corresponding potential across a two-wire circuit, it is evident that for the same size of conductor the total loss in volts could be doubled without increasing the percentage of loss in lamps. Furthermore, as the load on one side of the neutral conductor, when the system is balanced, is virtually in series with the load on the third side, the current in amperes is usually one-half the sum of the current required by all the lamps. If C be still taken as the total

***Note. Remember that V in Formulæ 1 to 4 represents the volts lost, but that E in Formula 5 represents the applied voltage.**

current in amperes (that is, the sum of the current required by all of the lamps) in Formula **1**, we shall have to divide this current by 2, to use the formula for calculating the two outside conductors for a three-wire system. Furthermore, we shall have to multiply the voltage lost in the lamps by 2, to obtain the voltage lost in the two outside conductors, for the reason that the potential of the outside conductors is double the potential required by the lamps themselves. In other words, Formula **1** will become:

$$CM = \frac{C \times D \times 21.6}{2 \times V \times 2}$$

$$= \frac{C \times D \times 21.6}{4\,V}, \qquad\qquad (6)$$

in which C = Sum of current required by all of the lamps on both sides of the neutral conductor;
D = Length of circuit—that is, of any one of the three conductors;
V = Loss allowed in the lamps, i. e., one-half the total loss in the two outside conductors.

In the same manner, all of the other formulæ may be adapted for making calculations for three-wire systems. Of course the calculation of a three-wire system could be made as if it were a two-wire system, by taking one-half the total number of lamps supplied, at one-half the voltage between the outside conductors.

It is understood, of course, that the size of the conductor in Formula **6** is the size of each of the two outside ones; but, inasmuch as the *Rules of the National Electric Code* require that for interior wiring the neutral conductor shall be at least equal in size to the outside conductors, it is not necessary to calculate the size of the neutral conductor. It must be remembered, however, that, in a three-wire system where the neutral conductor is made equal in capacity to the combined size of the two outside conductors, and where the two outside conductors are joined together, we have virtually a two-wire system arranged so that it can be converted into a three-wire system later. In this case the calculation is exactly the same as in the case of the two-wire circuits, except that one of the two conductors is split into two smaller wires of the same capacity. This is frequently done where isolated plants are installed, and where the generators are wound for 125 volts and it may be desired at times to take current from an outside three-wire 125-250-volt system.

METHOD OF PLANNING A WIRING INSTALLATION

The first step in planning a wiring installation, is to gather all the data which will affect either directly or indirectly the system of wiring and the manner in which the conductors are to be installed. These data will include: Kind of building; construction of building; space available for conductors; source and system of electric-current supply; and all details which will determine the method of wiring to be employed. These last items materially affect the cost of the work, and are usually determined by the character of the building and by commercial considerations.

Method of Wiring. In a modern fireproof building, the only system of wiring to be recommended is that in which the conductors are installed in rigid conduits; although, even in such cases, it may be desirable, and economy may be effected thereby, to install the larger feeder and main conductors exposed on insulators using weatherproof slow-burning wire. This latter method should be used, however, only where there is a convenient runway for the conductors, so that they will not be crowded and will not cross pipes, ducts, etc., and also will not have too many bends. Also, the local inspection authorities should be consulted before using this method.

For mills, factories, etc., wires exposed on cleats or insulators are usually to be recommended, although rigid conduit, flexible conduit, or armored cable may be desirable.

In finished buildings, and for extensions of existing outlets, where the wiring could not readily or conveniently be concealed, moulding is generally used, particularly where cleat wiring or other exposed methods of wiring would be objectionable. However, as has already been said, moulding should not be employed where there is any liability to dampness.

In finished buildings, particularly where they are of frame construction, flexible steel conduits or armored cable are to be recommended.

While in new buildings of frame construction, knob and tube wiring are frequently employed, this method should be used only where the question of first cost is of prime importance. While armored cable will cost approximately 50 to 100 per cent more than knob and

tube wiring, the former method is so much more permanent and is so much safer that it is strongly recommended.

Systems of Wiring. The system of wiring—that is, whether the two-wire or the three-wire system shall be used—is usually determined by the source of supply. If the source of supply is an isolated plant, with simple two-wire generators, and with little possibility of current being taken from the outside at some future time, the wiring in the building should be laid out on the two-wire system. If, on the other hand, the isolated plant is three-wire (having three-wire generators, or two-wire generators with balancer sets), or if the current is taken from an outside source, the wiring in the building should be laid out on a three-wire system.

It very seldom happens that current supply from a central station is arranged with other than the three-wire system inside of buildings, because, if the outside supply is alternating current, the transformers are usually adapted for a three-wire system. For small buildings, on the other hand, where there are only a few lights and where there would be only one feeder, the two-wire system is used. As a rule, however, when the current is taken from an outside source, it is best to consult the engineer of the central station supplying the current, and to conform with his wishes. As a matter of fact, this should be done in any event, in order to ascertain the proper voltage for the lamps and for the motors, and also to ascertain whether the central station will supply transformers, meters, and lamps—for, if these are not thus supplied, they should be included in the contract for the wiring.

Location of Outlets. It is not within the scope of this treatise to discuss the matter of *illumination*, but it is desirable, at this point, to outline briefly the method of procedure.

A set of plans, including elevation and details, if any, and showing decorative treatment of the various rooms, should be obtained from the Architect. A careful study should then be made by the Architect, the Owner, and the Engineer, or some other person qualified to make recommendations as to illumination. The location of the outlets will depend: *First,* upon the decorative treatment of the room, which determines the æsthetic and architectural effects; *second,* upon the type and general form of fixtures to be used, which should be previously decided on; *third,* upon the tastes of the owners or

occupants in regard to illumination in general, as it is found that tastes vary widely in regard to amount and kind of illumination.

The location of the outlets, and the number of lights required at each, having been determined, the outlets should be marked on the plans.

The Architect should then be consulted as to the location of the centers of distribution, the available points for the risers or feeders, and the available space for the branch circuit conductors.

In regard to the *rising points for the feeders and mains*, the following precautions should be used in selecting chases:

1. The space should be amply large to accommodate all the feeders and mains likely to rise at that given point. This seems trite and unnecessary, but it is the most usual trouble with chases for risers. Formerly architects and builders paid little attention to the requirements for chases for electrical work; but in these later days of 2-inch and 2½-inch conduit, they realize that these pipes are not so invisible and mysterious as the force they serve to distribute, particularly when twenty or more such conduits must be stowed away in a building where no special provision has been made for them.

2. If possible, the space should be devoted solely to electric wiring. Steam pipes are objectionable on account of their temperature; and these and all other pipes are objectionable in the same space occupied by the electrical conduits, for if the space proves too small, the electric conduits are the first to be crowded out.

The chase, if possible, should be continuous from the cellar to the roof, or as far as needed. This is necessary in order to avoid unnecessary bends or elbows, which are objectionable for many reasons.

In similar manner, the location of *cut-out cabinets or distributing centers* should fulfil the following requirements:

1. They should be accessible at all times.

2. They should be placed sufficiently close together to prevent the circuits from being too long.

3. Do not place them in too prominent a position, as that is objectionable from the Architect's point of view.

4. They should be placed as near as possible to the rising chases, in order to shorten the feeders and mains supplying them.

Having determined the system and method of wiring, the location of outlets and distributing centers, the next step is to lay out the *branch circuits* supplying the various outlets.

Before starting to lay out the branch circuits, a drawing showing the floor construction, and showing the space between the top of the beams and girders and the flooring, should be obtained from the Architect. In fireproof buildings of iron or steel construction, it is almost the invariable practice, where the work is to be concealed, to run the

conduits over the beams, under the rough flooring, carrying them between the sleepers when running parallel to the sleepers, and notching the latter when the conduits run across them (see Fig. 31). In wooden frame buildings, the conduits run parallel to the beams and to the furring (see Fig. 32); they are also sometimes run below the

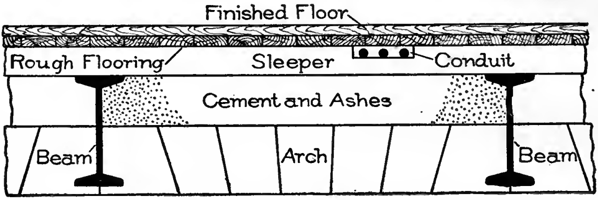

Fig. 31. Running Conductors Concealed under Floor in Fireproof Building.

beams. In the latter case the beams have to be notched, and this is allowable only in certain places, usually near the points where the beams are supported. The Architect's drawing is therefore necessary in order that the location and course of the conduits may be indicated on the plans.

The first consideration in laying out the branch circuit is the *number of outlets* and *number of lights* to be wired on any one branch circuit. The *Rules of the National Electric Code* (Rule 21-D) require that "no set of incandescent lamps requiring more than 660 watts, whether grouped on one fixture or on several fixtures or pendants, will be dependent on one cut-out." While it would be possible to have branch circuits supplying more than 660 watts, by placing various cut-outs at different points along the route of the branch circuit, so as to subdivide it into small sections to comply with the rule, this method is not recommended, except in certain cases, for exposed wiring in factories or mills. As a rule, the proper method is to have the cut-outs located at the center of distribution, and to limit each branch circuit to 660 watts, which corresponds to twelve or thirteen 50-watt lamps, twelve being the usual limit. Attention is called to the fact that the inspectors usually allow 50 watts for each socket connected to a branch circuit; and although 8-candle-power lamps may be placed at some of the outlets, the inspectors hold that the standard lamp is approximately 50 watts, and for that reason there is always the likelihood of a lamp of that capacity being used, and their inspec-

tion is based on that assumption. Therefore, to comply with the requirements, an allowance of not more than twelve lamps per branch circuit should be made.

In ordinary practice, however, it is best to reduce this number still further, so as to make allowance for future extensions or to increase the number of lamps that may be placed at any outlet. For this reason, it is wise to keep the number of the outlets on a circuit at the lowest point consistent with economical wiring. It has been proven by actual practice, that the best results are obtained by limiting the number to five or six outlets on a branch circuit. Of course, where all the outlets have a single light each, it is frequently necessary, for reasons of economy, to increase this number to eight, ten, and, in some cases, twelve outlets.

We have already referred to the location of the wires or conduits. This question is generally settled by the peculiarities of the construction of the building. It is necessary to know this, however, before laying out the circuit work, as it frequently determines the course of a circuit.

Now, as to the course of the circuit work, little need be said, as it is largely influenced by the relative position of the outlets, cut-

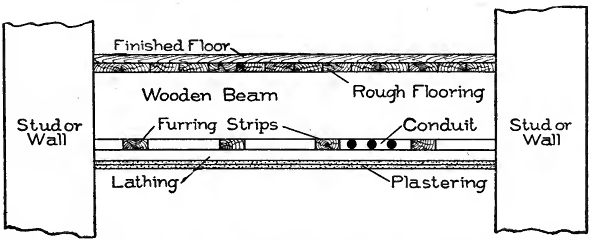

Fig. 32. Running Conductors Concealed under Floor in Wooden Frame Building.

outs, switches, etc. Between the cut-out box and the first outlet, and between the outlets, it will have to be decided, however, whether the circuits shall run at right angles to the walls of the building or room, or whether they shall run direct from one point to another, irrespective of the angle they make to the sleepers or beams. Of course, in the former case, the advantages are that the cost is somewhat less and the number of elbows and bends is reduced. If the

tubes are bent, however, instead of using elbows, the difference in cost is usually very slight, and probably does not compensate for the disadvantages that would result from running the tubes diagonally. As to the number of bends, if branch circuit work is properly laid out and installed, and a proper size of tube used, it rarely happens that there is any difference in "pulling" the branch circuit wires. It may happen, in the event of a very long run or one having a large number of bends, that it might be advisable to adopt a short and most direct route.

Up to this time, the location of the distribution centers has been made solely with reference to architectural considerations; but they must now be considered in conjunction with the branch circuit work.

It frequently happens that, after running the branch circuits on the plans, we find, in certain cases, that the position of centers of distribution may be changed to advantage, or sometimes certain groups may be dispensed with entirely and the circuits run to other points. We now see the wisdom of ascertaining from the Architect where cut-out groups may be located, rather than selecting particular points for their location.

As a rule, wherever possible, it is wise to limit the length of each branch circuit to 100 feet; and the number and location of the distributing centers should be determined accordingly.

It may be found that it is sometimes necessary and even desirable to increase the limit of length. One instance of this may be found in hall or corridor lights in large buildings. It is generally desirable, in such cases, to control the hall lights from one point; and, as the number of lights at each outlet is generally small, it would not be economical to run mains for sub-centers of distribution. Hence, in instances of this character, the length of runs will frequently exceed the limit named. In the great majority of cases, however, the best results are obtained by limiting the runs to 90 or 100 feet.

There are several good reasons for placing such a limit on the length of a branch circuit. To begin with, assuming that we are going to place a limit on the loss in voltage (drop) from the switchboard to the lamp, it may be easily proven that up to a certain reasonable limit it is more economical to have a larger number of distributing centers and shorter branch circuits, than to have fewer centers and longer circuits. It is usual, in the better class of work, to limit the

loss in voltage in any branch circuit to approximately one volt. Assuming this limit (one volt loss), it can readily be calculated that the number of lights at one outlet which may be connected on a branch circuit 100 feet long (using No. 14 B. & S. wire), is *four*; or in the case of outlets having a single light each, *five* outlets may be connected on the circuit, the first being 60 feet from the cut-out, the others being 10 feet apart.

These examples are selected simply to show that if the branch circuits are much longer than 100 feet, the loss must be increased to more than one volt, or else the number of lights that may be connected to one circuit must be reduced to a very small quantity, provided, of course, the size of the wire remains the same.

Either of these alternatives is objectionable—the first, on the score of regulation; and the second, from an economical standpoint. If, for instance, the loss in a branch circuit with all the lights turned on is four volts (assuming an extreme case), the voltage at which a lamp on that circuit burns will vary from four volts, depending on the number of lights burning at a time. This, of course, will cause the lamp to burn below candle-power when all the lamps are turned on, or else to diminish its life by burning above the proper voltage when it is the only lamp burning on the circuit. Then, too, if the drop in the branch circuits is increased, the sizes of the feeders and the mains must be correspondingly increased (if the total loss remains the same), thereby increasing their cost.

If the number of lights on the circuit is decreased, we do not use to good advantage the available carrying capacity of the wire.

Of course, one solution of the problem would be to increase the size of the wire for the branch circuits, thus reducing the drop. This, however, would not be desirable, except in certain cases where there were a few long circuits, such as for corridor lights or other special control circuits. In such instances as these, it would be better to increase the sizes of the branch circuit to No. 12 or even No. 10 B. & S. Gauge conductors, than to increase the number of centers of distribution for the sake of a few circuits only, in order to reduce the number of lamps (or loss) within the limit.

The method of calculating the loss in conductors has been given elsewhere; but it must be borne in mind, in calculating the loss of a branch circuit supplying more than one outlet, that separate calcu-

lations must be made for each portion of the circuit. That is, a calculation must be made for the loss to the first outlet, the length in this case being the distance from the center of distribution to the first outlet, and the load being the total number of lamps supplied by the circuit. The next step would be to obtain the loss between the first and second outlet, the length being the distance between the two outlets, and the load, in this case, being the total number of lamps supplied by the circuit, *minus* the number supplied by the first outlet; and so on. The loss for the total circuit would be the sum of these losses for the various portions of the circuit.

Feeders and Mains. If the building is more than one story, an elevation should be made showing the height and number of stories. On this elevation, the various distributing centers should be shown diagrammatically; and the current in amperes supplied through each center of distribution, should be indicated at each center. The next step is to lay out a tentative system of feeders and mains, and to ascertain the load in amperes supplied by each feeder and main. The estimated length of each feeder and main should then be determined, and calculation made for the loss from the switchboard to each center of distribution. It may be found that in some cases it will be necessary to change the arrangement of feeders or mains, or even the centers of distribution, in order to keep the total loss from the switchboard to the lamps within the limits previously determined. As a matter of fact, in important work, it is always best to lay out the entire work tentatively in a more or less crude fashion, according to the "cut and dried" method, in order to obtain the best results, because the entire layout may be modified after the first preliminary layout has been made. Of course, as one becomes more experienced and skilled in these matters, the final layout is often almost identical with the first preliminary arrangement.

TESTING

Where possible, two tests of the electric wiring equipment should be made, one after the wiring itself is entirely completed, and switches, cut-out panels, etc., are connected; and the second one after the fixtures have all been installed. The reason for this is that if a ground or short circuit is discovered before the fixtures are installed, it is more easily remedied; and secondly, because there is no division of

the responsibility, as there might be if the first test were made only after the fixtures were installed. If the test shows no grounds or short circuits before the fixtures are installed, and one does develop after they are installed, the trouble, of course, is that the short circuit or ground is one or more of the fixtures. As a matter of fact, it is a wise plan always to make a separate test of each fixture after it is delivered at the building and before it is installed.

While a *magneto* is largely used for the purpose of testing, it is at best a crude and unreliable method. In the first place, it does not give an indication, even approximately, of the total insulation resistance, but merely indicates whether there is a ground or short circuit, or not. In some instances, moreover, a magneto test has led to serious errors, for reasons that will be explained. If, as is nearly always the case, the magneto is an alternating-current instrument, it may sometimes happen—particularly in long cables, and especially where there is a lead sheathing on the cable—that the magneto will ring, indicating to the uninitiated that there is a ground or short circuit on the cable. This may be, and usually is, far from being the case; and the cause of the ringing of the magneto is not a ground or short circuit, but is due to the capacity of the cable, which acts as a condenser under certain conditions, since the magneto producing an alternating current repeatedly charges and discharges the cable in opposite directions, this changing of the current causing the magneto to ring. Of course, this defect in a magneto could be remedied by using a commutator and changing it to a direct-current machine; but as the method is faulty in itself, it is hardly worth while to do this.

A portable *galvanometer* with a resistance box and Wheatstone bridge, is sometimes employed; but this method is objectionable because it requires a special instrument which cannot be used for many other purposes. Furthermore, it requires more skill and time to use than the *voltmeter* method, which will now be described.

The advantage of the voltmeter method is that it requires merely a direct-current voltmeter, which can be used for many other purposes, and which all engineers or contractors should possess, together with a box of cells having a potential of preferably over 30 volts. The voltmeter should have a scale of not over 150 volts, for the reason that if the scale on which the battery is used covers too wide a range (say 1,000 volts) the readings might be so small as to make the test inac-

curate. A good arrangement would be to have a voltmeter having two scales—say, one of 60 and one of 600—which would make the voltmeter available for all practical potentials that are likely to be used inside of a building. If desired, a voltmeter could be obtained with three connections having three scales, the lowest scale of which would be used for testing insulation resistances.

Before starting a test, all of the fuses should be inserted and switches turned on, so that the complete test of the entire installation can be made. When this has been done, the voltmeter and battery should be connected, so as to obtain on the lowest scale of the voltmeter the electromotive force of the entire group of cells. This connection is shown in Fig. 33. Immediately after this has been done, the insulation resistance to be tested is placed in circuit, whether the insulation to be tested is a switchboard, slate panel-board, or the entire wiring installation; and the connections are made as shown in Fig. 34. A reading should then again be taken of the voltmeter; and the leakage is in proportion to the difference between the first and second readings of the voltmeter. The explanation given below will show how this resistance may be calculated: It is evident that the resistance in the first case was merely the resistance of the voltmeter and the internal resistance of the battery. As a rule, the internal resistance of the battery is so small in comparison with the resistance of the voltmeter and the external resistance, that it may be entirely neglected, and this will be done in the following calculation. In the second case, however, the total resistance in circuits is the resistance of the voltmeter and the battery, *plus* the entire insulation resistance on all the wires, etc., connected in circuit.

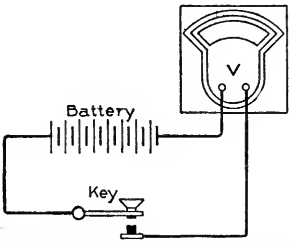

Fig. 33. Connections of Voltmeter and Battery for Testing Insulation Resistance.

To put this in mathematical form, the voltage of the cells may be indicated by the letter E; and the reading of the voltmeter when the insulation resistance is connected by the circuit, by the letter E'. Let R represent the resistance of the voltmeter and R_x represent the insulation resistance of the installation which we wish to measure.

It is a fact which the reader undoubtedly knows, that the E. M. F. as indicated by the voltmeter in Fig. 34 is inversely proportional to the resistance: that is, the greater the resistance, the lower will be the reading on the voltmeter, as this reading indicates the leakage or current passing through the resistance. Putting this in the shape of a formula, we have from the theory of proportion:

$$E : E' :: R + R_x : R;$$

or,

$$E' R + E' R_x = E R.$$

Transposing,

$$E' R_x = E R - E' R = R (E - E'),$$

and

$$R_x = \frac{R (E - E')}{E'}.$$

Or, expressed in words, the insulation resistance is equal to the resistance of the voltmeter *multiplied by* the difference between the first reading (or the voltage in the cells) and the second reading (or the reading of the voltmeter with the insulation resistance in series with the voltmeter), *divided by* this last reading of the voltmeter.

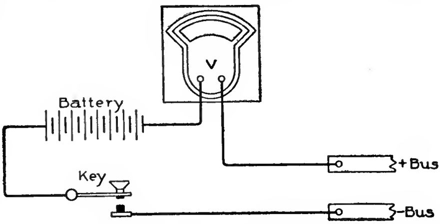

Fig. 34. Insulation Resistance Placed in Circuit, Ready for Testing.

Example. Assume a resistance of a voltmeter (R) of 20,000 ohms, and a voltage of the cells (E) of 30 volts; and suppose that the insulation resistance test of a wiring installation, including switchboard, feeders, branch circuits, panel-boards, etc., is to be made, the insulation resistance being represented by the letter R_x. By substituting in the formula

$$R_x = \frac{R (E - E')}{E'},$$

and assuming that the reading of the voltmeter with the insulation resistance connected is 5, we have:

$$R = \frac{20{,}000 \times (30-5)}{5} = 100{,}000 \text{ ohms.}$$

If the test shows an excessive amount of leakage, or a ground or

short circuit, the location of the trouble may be determined by the process of elimination—that is, by cutting out the various feeders until the ground or leakage disappears, and, when the feeder on which the trouble exists has been located, by following the same process with the branch circuits.

Of course, the larger the installation and the longer and more numerous the circuits, the greater the leakage will be; and the lower will be the insulation resistance, as there is a greater surface exposed for leakage. The *Rules of the National Electric Code* give a sliding scale for the requirements as to insulation resistance, depending upon the amount of current carried by the various feeders, branch circuits, etc. The rule of the *National Electric Code* (No. 66) covering this point, is as follows:

"The wiring in any building must test free from grounds; *i. e.*, the complete installation must have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) not less than that given in the following table:

Up to	5	amperes	4,000,000 ohms
"	10	"	2,000,000 "
"	25	"	800,000 "
"	50	"	400,000 "
"	100	"	200,000 "
"	200	"	100,000 "
"	400	"	50,000 "
"	800	"	25,000 "
"	1,600	"	12,500 "

"The test must be made with all cut-outs and safety devices in place. If the lamp sockets, receptacles, electroliers, etc., are also connected, only one-half of the resistances specified in the table will be required."

ALTERNATING-CURRENT CIRCUITS

It is not within the province of this chapter to treat the various alternating-current phenomena, but simply to outline the modifications which should be made in designing and calculating electric light wiring, in order to make proper allowance for these phenomena.

The most marked difference between alternating and direct current, so far as wiring is concerned, is the effect produced by self-induction, which is characteristic of all alternating-current circuits. This self-induction varies greatly with conditions depending upon the arrangement of the circuit, the medium surrounding the circuit, the devices or apparatus supplied by or connected in the circuit, etc.

For example, if a coil having a resistance of 100 ohms is included in the circuit, a current of one ampere can be passed through the coil with an electric pressure of 100 volts, if direct current is used; while it might require a potential of several hundred volts to pass a current of one ampere if alternating-current were used, depending upon the number of turns in the coil, whether it is wound on iron or some other non-magnetic material, etc.

It will be seen from this example, that greater allowance should be made for self-induction in laying out and calculating alternating-current wiring, if the conditions are such that the self-induction will be appreciable.

On account of self-induction, the two wires of an alternating-current circuit must never be installed in separate iron or steel conduits, for the reason that such a circuit would be virtually a *choke coil* consisting of a single turn of wire wound on an iron core, and the self-induction would not only reduce the current passing through the circuit, but also might produce heating of the iron pipe. It is for this reason that the *National Electric Code* requires conductors constituting a given circuit to be placed in the same conduit, if that conduit is iron or steel, whenever the said circuit is intended to carry, or is liable to carry at some future time, an alternating current. This does not mean, in the case of a two-phase circuit, that all four conductors need be placed in the same conduit, but that the two conductors of a given phase must be placed in the same conduit. If, however, the three-wire system be used for a two-phase system, all three conductors should be placed in the same conduit, as should also be the case in a three-wire three-phase system. Of course, in a single-phase two- or three-wire system, the conductors should all be placed in the same conduit.

In calculating circuits carrying alternating current, no allowance usually should be made for self-induction when the conductors of the same circuit are placed close together in an iron conduit. When, however, the conductors are run exposed, or are separated from each other, calculation should be made to determine if the effects of self-induction are great enough to cause an appreciable inductive drop. There are several methods of calculating this drop due to self-induction—one by formula, and one by a mathematical method which will be described.

Skin Effect. Skin effect in alternating-current circuits is caused by an incorrect distribution of the current in the wire, the current tending to flow through the outer portion of the wire, it being a well-known fact that in alternating currents, the current density decreases toward the center of the conductor, and that in large wires, the current density at the center of the conductor is relatively quite small.

The skin effect increases in proportion to the square of the diameter, and also in direct ratio to the frequency of the alternating current.

For conductors of No. 0000 B. & S. Gauge, and smaller, and for frequencies of 60 cycles per second, or less, the skin effect is negligible and is less than one-half of one per cent.

For very large cables and for frequencies above 60 cycles per second, the skin effect may be appreciable; and in certain cases, allowance for it should be made in making the calculation. In ordinary practice, however, it may be neglected. Table IX, taken from *Alternating-Current Wiring and Distribution*, by W. R. Emmet, gives the data necessary for calculating the skin effect. The figures given in the first and third columns are obtained by multiplying the size of the conductor (in circular mils) by the frequency (number of cycles per second); and the figures in the second and fourth columns show the factor to be used in multiplying the ohmic resistance, in order to obtain the combined resistance and skin effect.

TABLE IX
Data for Calculating Skin Effect

Product of Circular Mils × Cycles per Sec.	Factor	Product of Circular Mils × Cycles per Sec.	Factor
10,000,000	1.00	70,000,000	1.13
20,000,000	1.01	80,000,000	1.17
30,000,000	1.03	90,000,000	1.20
40,000,000	1.05	100,000,000	1.25
50,000,000	1.08	125,000,000	1.34
60,000,000	1.10	150,000,000	1.43

The factors given in this table, *multiplied by* the resistance to direct currents, will give the resistance to alternating currents for copper conductors of circular cross-section.

Mutual Induction. When two or more circuits are run in the same vicinity, there is a possibility of one circuit inducing an electromotive force in the conductors of an adjoining circuit. This effect may result in raising or lowering the E. M. F. in the circuit in which a

mutual induction takes place. The amount of this induced E. M. F. set up in one circuit by a parallel current, is dependent upon the current, the frequency, the lengths of the circuits running parallel to each other, and the relative positions of the conductors constituting the said circuits.

Under ordinary conditions, and except for long circuits carrying high potentials, the effect of mutual induction is so slight as to be negligible, unless the conductors are improperly arranged. In order to prevent mutual induction, the conductors constituting a given circuit should be grouped together. Figs. 35 to 39, inclusive, show

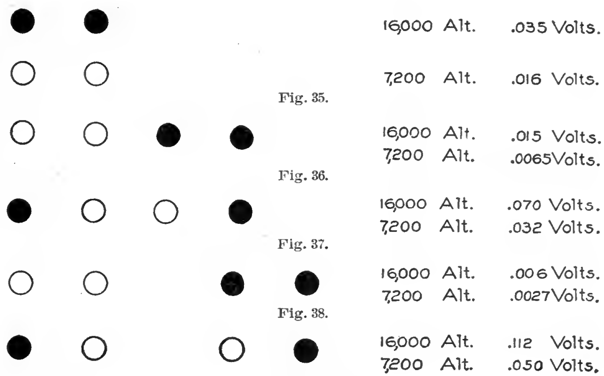

Fig. 35. Fig. 36. Fig. 37. Fig. 38. Fig. 39.

Various Groupings of Conductors in Two Two-Wire Circuits, Giving Various Effects of Induction.

five arrangements of two two-wire circuits; and show how relatively small the effect of first induction is when the conductors are properly arranged, as in Fig. 38, and how relatively large it may be when improperly arranged, as in Fig. 39. These diagrams are taken from a publication of Mr. Charles F. Scott, entitled *Polyphase Transmission,* issued by the Westinghouse Electric & Manufacturing Company.

Line Capacity. The effect of capacity is usually negligible, except in long transmission lines where high potentials are used; no calculations or allowance need be made for capacity, for ordinary circuits.

Calculation of Alternating-Current Circuits. In the instruction paper on "Power Stations and Transmission," a method is given for calculating alternating-current lines by means of formulæ, and data are given regarding power factor and the calculation of both single-phase and polyphase circuits. For short lines, secondary wiring, etc., however, it is probably more convenient to use the chart method devised by Mr. Ralph D. Mershon, described in the *American Electrician* of June, 1897, and partially reproduced as follows:

DROP IN ALTERNATING-CURRENT LINES

When alternating currents first came into use, when transmission distances were short and the only loads carried were lamps, the question of *drop* or *loss of voltage* in the transmitting line was a simple one, and the same methods as for direct current could without serious error be employed in dealing with it. The conditions existing in alternating practice to-day—longer distances, polyphase circuits, and loads made up partly or wholly of induction motors—render this question less simple; and direct-current methods applied to it do not lead to satisfactory results. Any treatment of this or of any engineering subject, if it is to benefit the majority of engineers, must not involve groping through long equations or complex diagrams in search of practical results. The results, if any, must be in available and convenient form. In what follows, the endeavor has been made to so treat the subject of drop in alternating-current lines that if the reader be grounded in the theory the brief space devoted to it will suffice; but if he do not comprehend or care to follow the simple theory involved, he may nevertheless turn the results to his practical advantage.

Calculation of Drop. Most of the matter heretofore published on the subject of drop treats only of the inter-relation of the E. M. F.'s involved, and, so far as the writer knows, there have not appeared in convenient form the data necessary for accurately calculating this quantity. Table X (page 47) and the chart (page 46) include, in a form suitable for the engineer's pocketbook, everything necessary for calculating the drop of alternating-current lines.

The chart is simply an extension of the vector diagram (Fig. 40), giving the relations of the E. M. F.'s of line, load and generator. In

Fig. 40, E is the generator E. M. F.; e, the E. M. F. impressed upon the load; c, that component of E which overcomes the back E. M. F. due to the impedance of the line. The component c is made up of two components at right angles to each other. One is a, the component overcoming the IR or back E. M. F. due to resistance of the line. The other is b, the component overcoming the reactance E. M. F. or back E. M. F. due to the alternating field set up around the wire by the current in the wire: The drop is the difference between E and e. It is d, the radial distance between two circular arcs, one of which is drawn with a radius e, and the other with a radius E.

The chart is made by striking a succession of circular arcs with O as a center. The radius of the smallest circle corresponds to e, the E. M. F. of the load, which is taken as 100 per cent. The radii of the succeeding circles increase by 1 per cent of that of the smallest circle; and, as the radius of the last or largest circle is 140 per cent of that of the smallest, the chart answers for drops up to 40 per cent of the E. M. F. delivered.

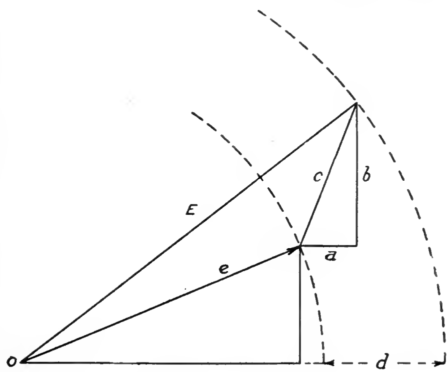

Fig. 40. Vector Diagram.

The terms *resistance volts, resistance E. M. F., reactance volts,* and *reactance E. M. F.*, refer, of course, to the voltages for overcoming the back E. M. F.'s due to resistance and reactance respectively. The figures given in the table under the heading "Resistance-Volts for One Ampere, etc." are simply the resistances of 2,000 feet of the various sizes of wire. The values given under the heading "Reactance-Volts, etc.," are, a part of them, calculated from tables published some time ago by Messrs. Houston and Kennelly. The remainder were obtained by using Maxwell's formula.

The explanation given in the table accompanying the chart

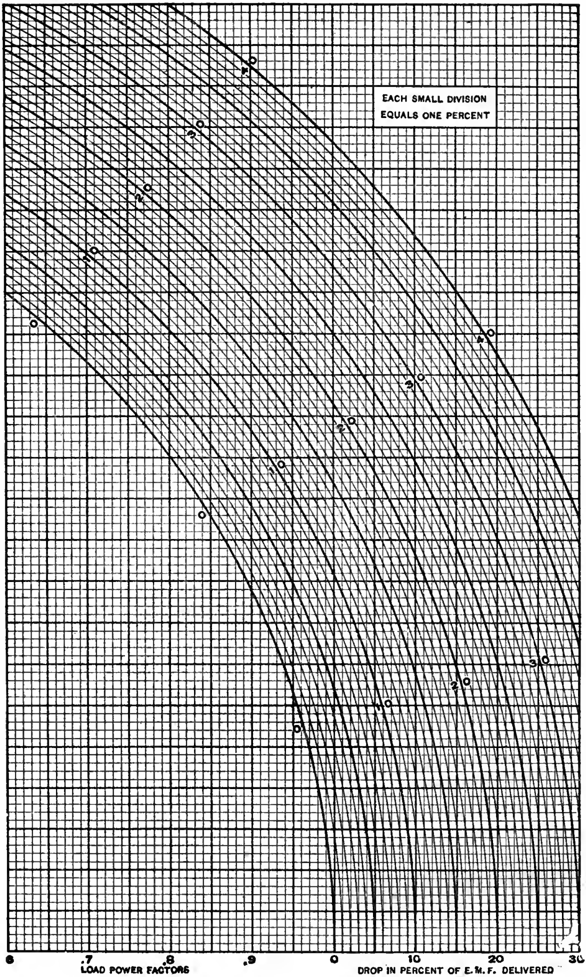

Chart for Calculating Drop in Alternating-Current Lines.

TABLE X

Data for Calculating Drop in Alternating-Current Lines

To be used in conjunction with Chart on opposite page.

By means of the table, calculate the *Resistance-Volts* and the *Reactance-Volts* in the line, and find what per cent each is of the E. M. F. delivered at the end of the line. Starting from the point on the chart where the vertical line corresponding with the power-factor of the load intersects the smallest circle, lay off in per cent the resistance E. M. F. horizontally and to the right; from the point thus obtained, lay off upward in per cent the reactance-E. M. F. The circle on which the last point falls gives the drop, in per cent, of the E. M. F. delivered at the end of the line. Every tenth circle arc is marked with the per cent drop to which it corresponds.

Throughout the table the lower figures in the squares give values for ONE MILE of line, corresponding to those of the upper figures for 1,000 feet of line.

Upper figures are REACTANCE-VOLTS in 1,000 ft. of Line (= 2,000 ft. of Wire) for One Ampere at 7,200 Alternations per Minute (60 Cycles per Second) for the distance given between Centers of Conductors.

Size of wire—B. & S.	Upper figures are Weight in Lbs. per 1,000 ft. Single Wire	Upper figures are RESISTANCE-VOLTS in 1,000 ft. of Line (2,000 ft. of wire) for One Ampere	½"	1"	2"	3"	6"	9"	12"	18"	24"	30"	36"
0000	639 3,376	.098 .518	.046 .243	.079 .417	.111 .586	.130 .687	.161 .850	.180 .951	.193 1.02	.212 1.12	.225 1.19	.235 1.24	.244 1.29
000	507 2,677	.124 .653	.052 .275	.085 .449	.116 .613	.135 .713	.167 .882	.185 .977	.199 1.05	.217 1.15	.230 1.22	.241 1.27	.249 1.32
00	402 2,123	.156 .824	.057 .301	.090 .475	.121 .639	.140 .739	.172 .908	.190 1.00	.204 1.08	.222 1.17	.236 1.25	.246 1.30	.254 1.34
0	319 1,685	.197 1.04	.063 .332	.095 .502	.127 .671	.145 .766	.177 .935	.196 1.04	.209 1.10	.228 1.20	.241 1.27	.251 1.33	.259 1.37
1	253 1,335	.248 1.31	.068 .359	.101 .533	.132 .687	.151 .797	.183 .966	.201 1.06	.214 1.13	.233 1.23	.246 1.30	.256 1.35	.265 1.40
2	201 1,059	.313 1.65	.074 .391	.106 .560	.138 .728	.156 .824	.188 .993	.206 1.09	.220 1.16	.238 1.26	.252 1.33	.262 1.38	.270 1.43
3	159 840	.394 2.08	.079 .417	.112 .591	.143 .755	.162 .856	.193 1.02	.212 1.12	.225 1.19	.244 1.29	.257 1.36	.267 1.41	.275 1.45
4	126 666	.497 2.63	.085 .449	.117 .618	.149 .787	.167 .882	.199 1.05	.217 1.15	.230 1.22	.249 1.32	.262 1.38	.272 1.44	.281 1.48
5	100 528	.627 3.31	.090 .475	.121 .639	.154 .813	.172 .908	.204 1.08	.223 1.18	.236 1.25	.254 1.34	.268 1.42	.278 1.47	.286 1.51
6	79 419	.791 4.18	.095 .502	.127 .671	.158 .834	.178 .940	.209 1.10	.228 1.20	.241 1.27	.260 1.37	.272 1.44	.283 1.49	.291 1.54
7	63 332	.997 5.27	.101 .533	.132 .697	.164 .866	.183 .966	.214 1.13	.233 1.23	.246 1.30	.265 1.40	.278 1.47	.288 1.52	.296 1.56
8	50 263	1.260 6.64	.106 .560	.138 .729	.169 .893	.188 .993	.220 1.16	.238 1.26	.252 1.33	.270 1.43	.284 1.50	.293 1.55	.302 1.60

(Table X) is thought to be a sufficient guide to its use, but a few examples may be of value.

Problem. Power to be delivered, 250 K.W.; E. M. F. to be delivered, 2,000 volts; distance of transmission, 10,000 feet; size of wire, No. 0; distance between wires, 18 inches; power factor of load, .8; frequency, 7,200 alternations per minute. Find the line loss and drop.

Remembering that the power factor is that fraction by which the apparent power of volt-amperes must be multiplied to give the true power, the apparent power to be delivered is

$$\frac{250 \text{ K.W.}}{.8} = 312.5 \text{ apparent K.W.}$$

The current, therefore, at 2,000 volts will be

$$\frac{312{,}500}{2{,}000} = 156.25 \text{ amperes.}$$

From the table of reactances under the heading "18 inches," and corresponding to No. 0 wire, is obtained the constant .228. Bearing the instructions of the table in mind, the reactance-volts of this line are, 156.25 (amperes) $\times$ 10 (thousands of feet) $\times$ .228 $=$ 356.3 volts, which is 17.8 per cent of the 2,000 volts to be delivered.

From the column headed "Resistance-Volts" and corresponding to No. 0 wire, is obtained the constant .197. The resistance-volts of the line are, therefore, 156.25 (amperes) $\times$ 10 (thousands of feet) $\times$ .197 $=$ 307.8 volts, which is 15.4 per cent of the 2,000 volts to be delivered.

Starting, in accordance with the instructions of the table, from the point where the vertical line (which at the bottom of the chart is marked "Load Power Factor" .8) intersects the inner or smallest circle, lay off horizontally and to the right the resistance-E. M. F. in per cent (15.4); and *from the point thus obtained,* lay off vertically the reactance-E. M. F. in per cent (17.8). The last point falls at about 23 per cent, as given by the circular arcs. This, then, is the drop, in per cent, of *the E. M. F. delivered.* The drop, in per cent, of the *generator* E. M. F. is, of course,

$$\frac{23}{100+23} = 18.7 \text{ per cent.}$$

The percentage *loss of power* in the line has not, as with direct current, the same value as the percentage drop. This is due to the fact that the line has reactance, and also that the apparent power

delivered to the load is not identical with the true power—that is, the load power factor is less than unity. The loss must be obtained by calculating $I^2 R$ for the line, or, what amounts to the same thing, by multiplying the resistance-volts by the current.

The resistance-volts in this case are 307.8, and the current 156.25 amperes. The loss is $307.8 \times 156.25 = 48.1$ K. W. The percentage *loss* is

$$\frac{48.1}{250 + 48.1} = 16.1 \text{ per cent.}$$

Therefore, for the problem taken, the *drop* is 18.7 per cent, and the *loss* is 16.1 per cent. If the problem be to find the size wire for a given drop, it must be solved by trial. Assume a size of wire and calculate the drop; the result in connection with the table will show the direction and extent of the change necessary in the size of wire to give the required drop.

The effect of the line reactance in increasing the drop should be noted. If there were no reactance, the drop in the above example would be given by the point obtained in laying off on the chart the resistance-E. M. F. (15.4) only. This point falls at 12.4 per cent, and the drop in terms of the generator E. M. F. would be

$$\frac{12.4}{112.4} = 11 \text{ per cent, instead of } 18.7 \text{ per cent.}$$

Anything therefore which will reduce reactance is desirable.

Reactance can be reduced in two ways. One of these is to diminish the distance between wires. The extent to which this can be carried is limited, in the case of a pole line, to the least distance at which the wires are safe from swinging together in the middle of the span; in inside wiring, by the danger from fire. The other way of reducing reactance is to split the copper up into a greater number of circuits, and arrange these circuits so that there is no inductive interaction. For instance, suppose that in the example worked out above, two No. 3 wires were used instead of one No. 0 wire. The resistance-volts would be practically the same, but the reactance-volts would be less in the ratio $\frac{1}{2} \times \frac{.244}{.228} = .535$, since each circuit would bear half the current the No. 0 circuit does, and the constant for No. 3 wire is .244, instead of .228—that for No. 0. The effect of subdividing the copper is also shown if in the example given it is desired to reduce the drop

to, say, one-half. Increasing the copper from No. 0 to No. 0000 will not produce the required result, for, although the resistance-volts will be reduced one-half, the reactance-volts will be reduced only in the ratio $\frac{.212}{.228}$. If, however, *two* inductively independent circuits of No. 0 wire be used, the resistance- and reactance-volts will both be reduced one-half, and the drop will therefore be diminished the required amount.

The component of drop due to reactance is best diminished by subdividing the copper or by bringing the conductors closer together. It is little affected by change in size of conductors.

An idea of the manner in which changes of power factor affect drop is best gotten by an example. Assume distance of transmission, distance between conductors E. M. F., and frequency, the same as in the previous example. Assume the *apparent* power delivered the same as before, and let it be constant, but let the power factor be given several different values; the true power will therefore be a variable depending upon the value of the power factor. Let the size of wire be No. 0000. As the apparent power, and hence the current, is the same as before, and the line resistance is one-half, the resistance-E. M. F. will in this case be

$$\frac{15.4}{2}, \text{ or } 7.7 \text{ per cent of the E. M. F. delivered.}$$

Also, the reactance-E. M. F. will be

$$\frac{.212 \times 17.8}{.228} = 16.5 \text{ per cent.}$$

Combining these on the chart for a power factor of .4, and deducing the drop, in per cent, of the generator E. M. F., the value obtained is 15.3 per cent; with a power factor of .8, the drop is 14 per cent; with a power factor of unity, it is 8 per cent. If in this example the *true* power, instead of the *apparent* power, had been taken as constant, it is evident that the values of drop would have differed more widely, since the current, and hence the resistance- and reactance-volts, would have increased as the power factor diminished. The condition taken more nearly represents that of practice.

If the line had resistance and no reactance, the several values of drop, instead of 15.3, 14, and 8, would be 3.2, 5.7, and 7.2 per cent respectively, showing that for a load of lamps the drop will not

be much increased by reactance; but that with a load, such as induction motors, whose power factor is less than unity, care should be taken to keep the reactance as low as practicable. In all cases it is advisable to place conductors as close together as good practice will permit.

When there is a transformer in circuit, and it is desired to obtain the combined drop of transformer and line, it is necessary to know the resistance- and reactance-volts of the transformer. The resistance-volts of the combination of line and transformer are the sum of the resistance-volts of the line and the resistance-volts of the transformer. Similarly, the reactance-volts of the line and transformer are the sum of their respective reactance-volts. The resistance- and reactance-E. M. F.s of transformers may usually be obtained from the makers, and are ordinarily given in per cent.* These percentages express the values of the resistance- and reactance-E. M. F.'s when the transformer delivers its normal *full-load* current; and they express these values in terms of the normal *no-load* E. M. F. of the transformer.

Consider a transformer built for transformation between 1,000 and 100 volts. Suppose the resistance- and reactance-E. M. F.'s given are 2 per cent and 7 per cent respectively. Then the corresponding voltages when the transformer delivers full-load current, are 2 and 7 volts or 20 and 70 volts according as the line whose drop is required is connected to the low-voltage or high-voltage terminals. These values, 2—7 and 20—70, hold, no matter at what voltage the trans-

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*When the required values cannot be obtained from the makers, they may be measured. Measure the resistance of both coils. If the line to be calculated is attached to the high-voltage terminals of the transformer, the equivalent resistance is that of the high-voltage coil, *plus* the resistance obtained by *increasing* in the square of the ratio of transformation the measured resistance of the low-voltage coil That is, if the ratio of transformation is 10, the equivalent resistance referred to the high-voltage circuit is the resistance of the high-voltage coil, *plus* 100 times that of the low-voltage coil. This equivalent resistance multiplied by the high-voltage current gives the transformer resistance-volts referred to the high-voltage circuit. Similarly, the equivalent resistance referred to the low-voltage circuit is the resistance of the low-voltage coil, *plus* that of the high-voltage coil *reduced* in the square of the ratio of transformation. It follows, of course, from this, that the values of the resistance-volts referred to the two circuits bear to each other the ratio of transformation. To obtain the reactance-volts, short-circuit one coil of the transformer and measure the voltage necessary to force through the other coil its normal current at normal frequency. The result is, nearly enough, the reactance-volts. It makes no difference which coil is short-circuited, as the results obtained in one case will bear to those in the other the ratio of transformation. If a close value is desired, subtract from the square of the voltage reading the square of the *resistance*-volts, and take the square root of the difference as the reactance-volts.

former is operated, since they depend only upon the strength of current, providing it is of the normal frequency. If any other than the full-load current is drawn from the transformer, the reactance- and resistance-volts will be such a proportion of the values given above as the current flowing is of the full-load current. It may be noted, in passing, that when the resistance- and reactance-volts of a transformer are known, its regulation may be determined by making use of the chart in the same way as for a line having resistance and reactance.

As an illustration of the method of calculating the drop in a line and transformer, and also of the use of table and chart in calculating low-voltage mains, the following example is given:

Problem. A single-phase induction motor is to be supplied with 20 amperes at 200 volts; alternations, 7,200 per minute; power factor, .78. The distance from transformer to motor is 150 feet, and the line is No. 5 wire, 6 inches between centers of conductors. The transformer reduces in the ratio $\frac{2{,}000}{200}$, has a capacity of 25 amperes at 200 volts, and, when delivering this current and voltage, its resistance-E. M. F. is 2.5 per cent, its reactance-E. M. F. 5 per cent. Find the drop.

The reactance of 1,000 feet of circuit consisting of two No. 5 wires, 6 inches apart, is .204. The reactance-volts therefore are

$$.204 \times \frac{150}{1{,}000} \times 20 = .61 \text{ volts.}$$

The resistance-volts are

$$.627 \times \frac{150}{1{,}000} \times 20 = 1.88 \text{ volts.}$$

At 25 amperes, the resistance-volts of the transformer are 2.5 per cent of 200, or 5 volts. At 20 amperes, they are $\frac{20}{25}$ of this, or 4 volts. Similarly, the transformer reactance-volts at 25 amperes are 10, and at 20 amperes are 8 volts. The combined reactance-volts of transformer and line are $8 + .61 = 8.61$, which is 4.3 per cent of the 200 volts to be delivered. The combined resistance-volts are $1.88 + 4$, or 5.88, which is 2.94 per cent of the E. M. F. to be delivered. Combining these quantities on the chart with a power factor of .78, the drop is 5 per cent of the delivered E. M. F.,

$$\text{or } \frac{5}{105} = 4.8 \text{ per cent}$$

of the impressed E. M. F. The transformer must be supplied with

$$\frac{2,000}{.952} = 2,100 \text{ volts},$$

in order that 200 volts shall be delivered to the motor.

Table X (page 47) is made out for 7,200 alternations, but will answer for any other number if the values for reactance be changed in direct proportion to the change in alternations. For instance, for 16,000 alternations, multiply the reactances given by $\frac{16,000}{7,200}$. For other distances between centers of conductors, interpolate the values given in the table. As the reactance values for different sizes of wire change by a constant amount, the table can, if desired, be readily extended for larger or smaller conductors.

The table is based on the assumption of sine currents and E. M. F.'s. The best practice of to-day produces machines which so closely approximate this condition that results obtained by the above methods are well within the limits of practical requirements.

Polyphase Circuits. So far, single-phase circuits only have been dealt with. A simple extension of the methods given above adapts them to the calculation of polyphase circuits. A four-wire *quarter-phase* (two-phase) transmission may, so far as loss and regulation are concerned, be replaced by two single-phase circuits identical (as to size of wire, distance between wires, current, and E. M. F.) with the two circuits of the quarter-phase transmission, provided that in both cases there is no inductive interaction between circuits. Therefore, to calculate a four-wire, quarter-phase transmission, compute the single-phase circuit required to transmit one-half the power at the same voltage. The quarter-phase transmission will require two such circuits.

A three-wire, *three-phase* transmission, of which the conductors are symmetrically related, may, so far as loss and regulation are concerned, be replaced by two single-phase circuits having no inductive interaction, and identical with the three-phase line as to size, wire, and distance between wires. Therefore, to calculate a three-phase transmission, calculate a single-phase circuit to carry one-half the load at the same voltage. The three-phase transmission will require three wires of the size and distance between centers as obtained for the single-phase.

A three-wire, quarter-phase transmission may be calculated

exactly as regards loss, and *approximately* as regards drop, in the same way as for three-phase. It is possible to exactly calculate the drop, but this involves a more complicated method than the approximate one. The error by this approximate method is generally small. It is possible, also, to get a somewhat less drop and loss with the same copper by proportioning the cross-section of the middle and outside wires of a three-wire, quarter-phase circuit to the currents they carry, instead of using three wires of the same size. The advantage, of course, is not great, and it will not be considered here.

WIRING AN OFFICE BUILDING

The building selected as a typical sample of a wiring installation is that of an office building located in Washington, D. C. The figures shown are reproductions of the plans actually used in installing the work.

The building consists of a basement and ten stories. It is of fireproof construction, having steel beams with terra-cotta flat arches. The main walls are of brick and the partition walls of terra-cotta blocks, finished with plaster. There is a space of approximately five inches between the top of the iron beams and the top of the finished floor, of which space about three inches was available for running the electric conduits. The flooring is of wood in the offices, but of concrete, mosaic, or tile in the basement, halls, toilet-rooms, etc.

The electric current supply is derived from the mains of the local illuminating company, the mains being brought into the front of the building and extending to a switchboard located near the center of the basement.

As the building is a very substantial fireproof structure, the only method of wiring considered was that in which the circuits would be installed in iron conduits.

Electric Current Supply. The electric current supply is direct current, two-wire for power, and three-wire for lighting, having a potential of 236 volts between the outside conductors, and 118 volts between the neutral and either outside conductor.

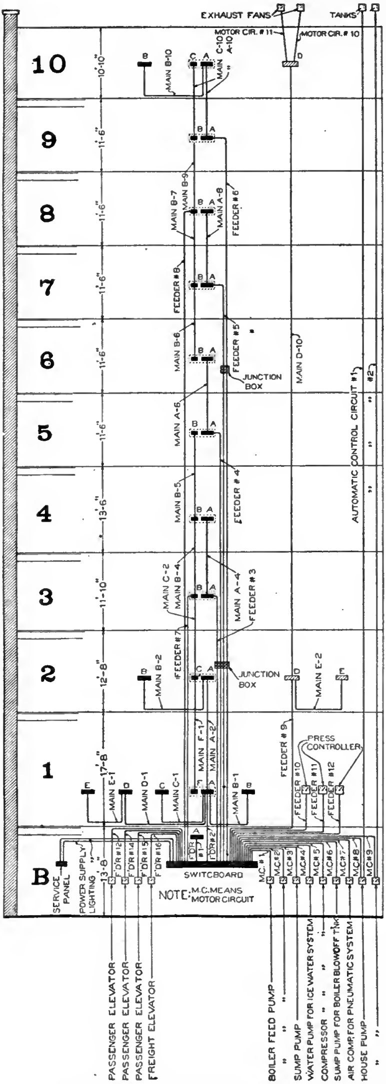
Switchboard. On the switchboard in the basement are mounted wattmeters, provided by the local electric company, and the various switches required for the control and operation of the lighting and power feeders. There are a total of ten triple-pole switches for lighting, and eighteen for power. An indicating voltmeter and ampere meter are also placed in the switchboard. A voltmeter is provided with a double-throw switch, and so arranged as to measure the potential across the two outside conductors, or between the neutral conductor and either of the outside conductors. The ampere meter is arranged with two shunts, one being placed in each outside leg; the shunts are connected with a double-pole, double-throw switch, so that the ampere meter can be connected to either shunt and thus measure the current supplied on each side of the system.

Character of Load. The building is occupied partly as a newspaper office, and there are several large presses in addition to the usual linotype machines, trimmers, shavers, cutters, saws, etc. There are also electrically-driven exhaust fans, house pumps, air-compressors, etc. The upper portion of the building is almost entirely devoted to offices rented to outside parties. The total number of motors supplied was 55; and the total number of outlets, 1,100, supplying 2,400 incandescent lamps and 4 arc lamps.

Feeders and Mains. The arrangement of the various feeders and mains, the cut-out centers, mains, etc., which they supply, are shown diagrammatically in Fig. 41, which also gives in schedule the sizes of feeders, mains, and motor circuits, and the data relating to the cut-out panels.

Although the current supply was to be taken from an outside source, yet, inasmuch as there was a probability of a plant being installed in the building itself at some future time, the three-wire system of feeders and mains was designed, with a neutral conductor equal to the combined capacity of the two outside conductors, so that 120-volt two-wire generators could be utilized without any change in the feeders.

Basement. The plan of the basement, Fig. 42, shows the branch circuit wiring for the outlets in the basement, and the location of the main switchboard. It also shows the trunk cables for the interconnection system serving to provide the necessary wires for telephones,



FEEDERS

NO.	END AT FLOOR	CUT-OUT	BRANCH CIR.	LIGHTS	LENGHT-FT (ONE WAY)	LOSS IN VOLTS	SIZE OF WIRE: NO. MIDDLE COND'R	SIZE OF WIRE: NO. OUTSIDE COND'R	INSIDE DIA. OF CONDUIT ALLOWED *
1	BASMT	A	18	115	48	0.84	2	4	1.25"
2	1 ST	"	83	533	88	1.18	400000	4-0	2.5"
3	3 RD	"	43	288	119	1.68	4-0	0	2"
4	5 TH	"	44	296	147	1.78	250000	2-0	2.5"
5	7 TH	"	"	292	173	1.72	300000	3-0	"
6	9 TH	"	124	365	200	1.61	450000	250000	3"
7	3 RD	B	26	131	119	1.5	0	3	1.5"
8	8 TH	"	27	128	185	1.8	2-0	2	2"
L.S.	SW.B	"		2165	138	1.5	4000000	2000000	***
9	2 ND	D			148		400000		3"
10	PRESS				83		700000		**
11	"				118		"		"
12	"				"		"		"
13	PASS.ELV.				58		4-0		2"
14	"				"		"		"
15	"				"		"		"
16	FRGT ELV.				148		"		"
P.S.	SW.B				138		2000000		****

* ALL CONDUCTORS IN ONE CONDUIT.
** SEPARATE CONDUIT FOR EACH CONDUCTOR
*** THIS FEEDER IS TO BE DIVIDED INTO FOUR (4)
" CONDUCTORS OF #2000000 C.M. EACH.
" EACH CONDUCTOR IS TO BE INSTALLED IN A SEP-
" ARATE 3" (INSIDE DIAM.) CONDUIT
L.S.=LIGHTING SUPPLY
P.S.=POWER "
**** SEPARATE 3" (INSIDE DIAM.) CONDUIT FOR EACH
" CONDUCTOR

MAINS

MAINS	SUPPLIED BY: FEEDER #	SUPPLIED BY: CUT OUT	SUPPLIED BY: FLOOR	LIGHTS	LENGTH-FT (ONE WAY)	LOSS IN VOLTS	SIZE OF WIRE: NO. MIDDLE COND'R	SIZE OF WIRE: NO. OUTSIDE COND'R	INSIDE DIA. OF CONDUIT ALLOWED *
A-2	2	A	1 ST	284	63	0.72	250000	2-0	2.5"
A-4	3	"	3 RD	147	18	0.41	2	4	1.25"
A-6	4	"	5 TH	146	"	0.4	"	"	"
A-8	5	"	7 TH	"	"	"	"	"	"
A-10	6	"	9 TH	171	"	0.29	0	3	1.5"
B-1	2	"	1 ST	76	70	0.51	"	"	"
B-2	"	"	"	206	58	0.58	4-0	0	2"
B-10	6	"	10 TH	87	44	0.37	0	3	1.5"
D-1	2	"	1 ST	120	12	0.22	2	4	1.25"
C-1	"	"	"	70	44	0.30	0	3	1.5"
F-1	7	C	2 ND	22	61	0.41	8	10	1"
C-2	"	B	3 RD	47	18	0.52	"	"	"
B-4	"	"	"	56	"	0.60	"	"	"
B-5	"	"	4 TH	28	"	0.31	"	"	"
B-6	8	"	7 TH	32	"	0.35	"	"	"
B-7	"	"	8 TH	56	"	0.60	"	"	"
B-9	"	"	"	44	"	0.48	"	"	"
C-10	"	"	9 TH	16	"	0.28	10	12	"
E-1	2	A	1 ST	61	92	0.86	2	4	1.25"
E-2	9	D	2 ND		84		0	0	1.5"
D-10	"	"	"		108		2	2	1.25"

* ALL CONDUCTORS IN ONE CONDUIT

MOTOR CIRCUITS

NO.	SUPPLIED BY: FEEDER	SUPPLIED BY: CUTOUT	SUPPLIED BY: FLOOR	H.P. SUPPLIED	CURRENT IN AMP.	LENGTH IN FEET (ONE WAY)	SIZE OF WIRE	INSIDE DIAM. OF CONDUIT ALLOWED *
1			BSMT	15	60	74	2	1.25"
2			"	"	"	"	"	"
3			"	5	20	50	8	1"
4			"	"	"	40	"	"
5			"	15	60	"	2	1.25"
6			"	3	12	48	10	0.75"
7			"		20	"	8	1"
8			"	15	60	80	2	1.25"
9	MAIN		"	"	"	"	"	"
10	D-10	D	10 TH	7.5	30	134	6	1"
11	"	"	"	"	"	28	"	"

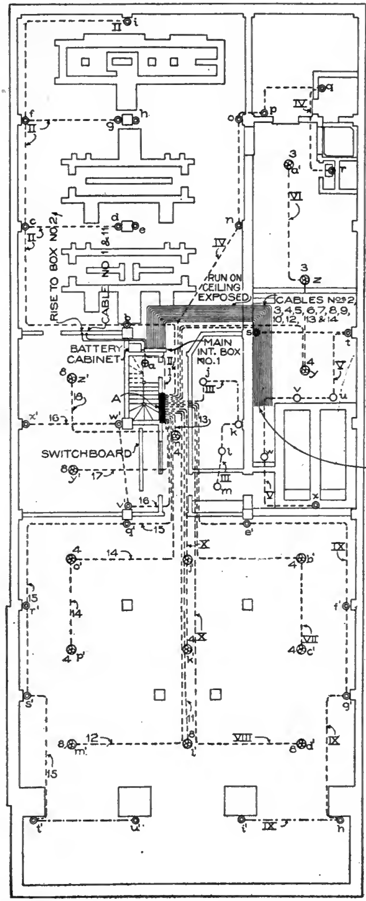
* BOTH CONDUCTORS IN ONE CONDUIT

CUT-OUTS

NAME	FLOOR	MAINS	BRANCH CIRCUITS	P.B. SWITCHES	METERS	T.P.S.T. 25 AMP.	T.P.S.T. 50 "	T.P.S.T. 100 "	T.P.S.T. 150 "	T.P.S.T. 200 "	D.P.S.T. 25 "	D.P.S.T. 50 "	D.P.S.T. 100 "	D.P.S.T. 125 "	D.P.S.T. 150 "
A	BSMT		20	10											
"	1 ST	4					2	1		1					
B	"		10	10											
C	"		"	"											
D	"	1	12	8			2								
E	"		"	4											
F	"		8	6											
A	2 ND	1	16	1			1*		1						
B	"		32	3											
C	"	1	4	4		2									
D	"	1									24		1	1	
E	"										4	6			
A	3 RD	1	22	1				2							
B	"	2	4	4		3									
A	4 TH		24	1											
B	"	1	4	4		2									
A	5 TH	1	24	1				2							
B	"		4	4											
A	6 TH		28	1											
B	"		4	4											
A	7 TH	1	24	1				2							
B	"	1	4	4		2									
A	8 TH		24	1											
B	"	2	4	4		3									
A	9 TH	1	24	1				1*	1						
B	"	1	4	4		2									
A	10 TH	1	24	1			1*	1							
B	"		16	1											
C	"		4	4											
D	"										4	2			

* MAIN SWITCH

Fig. 41. Wiring of an Office Building. Diagram Showing Arrangement of Feeders and Mains, Cut-Out Centers, etc.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A	F'D'R NO-1	1	a	1	1	
II	"	"	3	bcdefghi	8	8	
III	"	"	1	jklm	4	4	
IV	"	"	1	nopqr	5	5	
V	"	"	1	stuvwx	6	6	
VI	"	"	1	yza'	3	10	S at A
VII	"	"	1	b'c'	2	8	" " "
VIII	"	"	1	d'	1	8	" " "
IX	"	"	1	e'f'g'h'i'	5	5	
X	"	"	1	j'k'	2	8	S at A
11	"	"	1	l'	1	8	" " "
12	"	"	1	m'	1	8	" " "
13	"	"	1	n'	1	4	" " "
14	"	"	1	o'p'	2	8	" " "
15	"	"	1	q'r's't'u'	5	5	
16	"	"	1	v'w'x'	3	3	
17	"	"	1	y'	1	8	S at A
18	"	"	1	z'	1	8	" " "
					52	115	

CABLE NO. 2 RISES TO 2nd FLOOR
" " 3 " " 3rd "
" " 4 " " 4th "
" " 5 " " 5th "
" " 6 " " 6th "
" " 7 " " 7th "
" " 8 " " 8th "
" " 9 " " 9th "
" " 10 " " 10th "
" " 12 " " 2nd "
" " 13 " " 5th "
" " 14 " " 8th "

Key Showing Explanation of Various Symbols used in Figs. 41 to 46 Inclusive

- Ceiling Chandelier
- Wall Bracket
- Gooseneck Bracket
- Wall Socket
- Drop Cord
- Arc Lamp
- Cooper-Hewitt Lamp
- Cluster
- Floor Outlet
- Desk Light
- Extension Outlet
- Push Button Switch
- Snap Switch
- Junction Box
- Electric Clock
- Master Clock
- Motor Starter
- Cut Out Panel
- Interconnection Box
- Power Panel
- Pull Box
- Circuit under Floor
- " " above
- " on Ceiling Exposed
- Service Line under Floor

Fig. 42. Wiring an Office Building. Basement Plan Showing Branch Circuit Wiring for Outlets in Basement, Location of Main Switchboard, and Trunk Cables of the Interconnection System Providing Wires for Telephone, Ticker, and Messenger Call Service, etc,

tickers, messenger calls, etc., in all the rooms throughout the building, as will be described later.

To avoid confusion, the feeders were not shown on the basement plan, but were described in detail in the specification, and installed in accordance with directions issued at the time of installation. The electric current supply enters the building at the front, and a service switch and cut-out are placed on the front wall. From this point, a two-wire feeder for power and a three-wire feeder for lighting, are run to the main switchboard located near the center of the basement. Owing to the size of the conduits required for these supply feeders, as well as the main feeders extending to the upper floors of the building, the said conduits are run exposed on substantial hangers suspended from the basement ceiling.

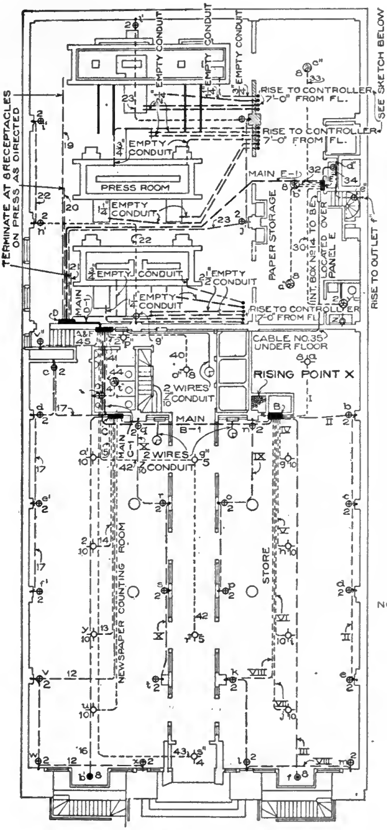
First Floor. The rear portion of the building from the basement through the first floor, Fig. 43, and including the mezzanine floor, between the first and second floors, at the rear portion of the building only, is utilized as a press room for several large and heavy, modern newspaper presses. The motors and controllers for these presses are located on the first floor. A separate feeder for each of these press motors is run directly from the main switchboard to the motor controller in each case. Empty conduits were provided, extending from the controllers to the motor in each case, intended for the various control wires installed by the contractor for the press equipments.

One-half of the front portion of the first floor is utilized as a newspaper office; the remaining half, as a bank.

Second Floor. The rear portion of the second floor, Fig. 44, is occupied as a composing and linotype room, and is illuminated chiefly by means of drop-cords from outlets located over the linotype machines and over the compositors' cases. Separate $\frac{1}{8}$-horse-power motors are provided for each linotype machine, the circuits for the same being run underneath the floor.

Upper Floors. A typical plan (Fig. 45) is shown of the upper floors, as they are similar in all respects with the exception of certain changes in partitions, which are not material for the purpose of illustration or for practical example. The circuit work is sufficiently intelligible from the plan to require no further explanation.

Interconnection System. Fig. 46 is a diagram of the interconnection system, showing the main interconnection box located in the



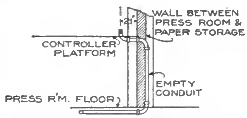
NOTE: ALL CONDUITS FOR THE PRESSES MUST COME THROUGH THE CONTROLLER PLATFORM 21" FROM THE WALL.

ALL CONDUITS ARE TO TERMINATE IN PRESS AS DIRECTED.

SCHEDULE OF CIRCUITS

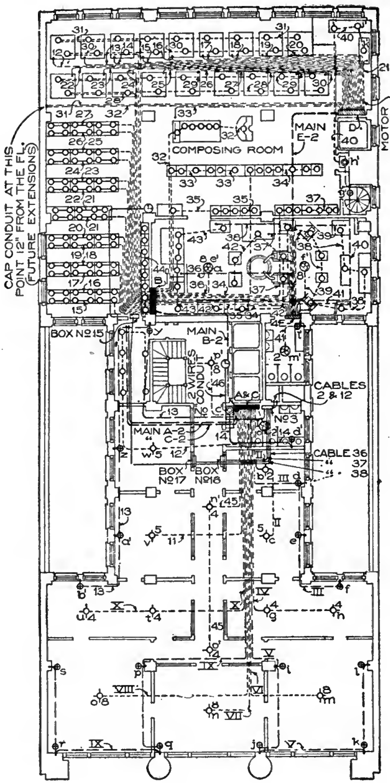
NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	B	F'D'R No. 2	1	a	1	8	S at B
II	"	"	1	bcde	4	8	" " "
III	"	"	1	f	1	8	" " "
IV	"	"	1	g	1	10	" " "
V	"	"	1	h	1	10	" " "
VI	"	"	1	i	1	10	" " "
VII	"	"	1	j	1	10	" " "
VIII	"	"	1	klm	3	6	" " "
IX	"	"	1	nop	3	6	" " "
			1		16	76	
X	C	C-1	1	qrst	4	8	S at C
11	"	"	1	u	1	10	" " "
12	"	"	1	vwx	3	6	" " "
13	"	"	1	y	1	10	" " "
14	"	"	1	z	1	10	" " "
15	"	"	1	a'	1	10	" " "
16	"	"	1	b'	1	8	" " "
17	"	"	1	c'd'e'f'	4	8	" " "
					16	70	
19	D	D-1	1	8 Receptacles	8	8	
20	"	"	1		8	8	
21	"	"	1		8	8	
22	"	"	1	g'h'i'	3	6	S at D
23	"	"	1	j'k'l'	3	6	" " "
24							
25							
26	SEE MEZZ. PLAN						
27							
28							
29							
30	E	E-1	1	y'z'	2	3	S at E
31	"	"	1	a"	1	8	" " "
32	"	"	1	b"	1	8	" " "
33	"	"	1	c"	1	8	" " "
34	"	"	1	d"e"f", g",	4	4	" " "
35							
36							
37	SEE MEZZ. PLAN						
38							
39							
40	F		1	o"	1	8	S at F
41	"	"	1	p"	1	2	" " "
42	"	"	1	q"r"	2	10	" " "
43	"	"	1	s"	1	4	" " "
44	"	"	1	t"u"	2	6	" " "
45	"	"	1	v"	1	1	" " "
					8	31	" " "

NOTE: THE CLOCKS IN STORE AND COUNTING ROOM ARE TO BE LOCATED AS DIRECTED BY ARCHITECT.



SKETCH SHOWING ROUTE OF EMPTY CONDUIT'S RISING TO CONTROLLER PLATFORM IN PRESS ROOM.

Fig. 43. Wiring of an Office Building.
First-Floor Plan, Showing Press Room in Rear, Containing Motors and Controllers for Newspaper Presses, Fed Directly from Main Switchboard in Basement; also, in front, Newspaper Counting Room and Bank Offices.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A	A-2	1	a	1	2	S at A
II	"	"	1	bc	2	7	
III	"	"	1	def	3	3	
IV	"	"	1	gh	2	8	
V	"	"	1	ijkl	4	4	
VI	"	"	1	m	1	8	
VII	"	"	1	n	"	"	
VIII	"	"	1	o	"	"	
IX	"	"	1	pqrs	4	4	
X	"	"	1	tu	2	8	
11	"	"	1	v	1	5	
12	"	"	1	w & 6 Drop Cds	7	11	
13	"	"	1	yz a'b'	4	4	
14	"	"	1	c'd'	2	2	
					30	78	
15	B	B-2	1	Drop Cords	6	6	
16	"	"	1	" "	"	"	
17	"	"	1	" "	"	"	
18	"	"	1	" "	"	"	
19	"	"	1	" "	"	"	
20	"	"	1	" "	"	"	
21	"	"	1	" "	10	10	
22	"	"	1	" "	6	6	
23	"	"	1	" "	"	"	
24	"	"	1	" "	"	"	
25	"	"	1	" "	"	"	
26	"	"	1	" "	"	"	
27	"	"	1	" "	"	"	
28	"	"	1	" "	9	9	
29	"	"	1	" "	"	"	
30	"	"	1	" "	"	"	
31	"	"	1	" "	"	"	
32	"	"	1	" "	7	7	
33	"	"	1	" "	6	6	
34	"	"	1	" "	7	7	
35	"	"	1	" "	6	6	
36	"	"	1	e'	1	8	S at B
37	"	"	1	Drop Cords	7	7	
38	"	"	1	" "	9	9	
39	"	"	1	f'	1	8	S at B
40	"	"	1	g'h'i'j'k'	5	5	
41	"	"	1	l'm'	2	3	S at B
42	"	"	1	Drop Cords	7	7	
43	"	"	1	" "	7	7	
44	"	"	1	" "	8	8	
45	C	C-2	1	n'o'	2	8	S at C
46	"	"	1	p'	1	8	" " "

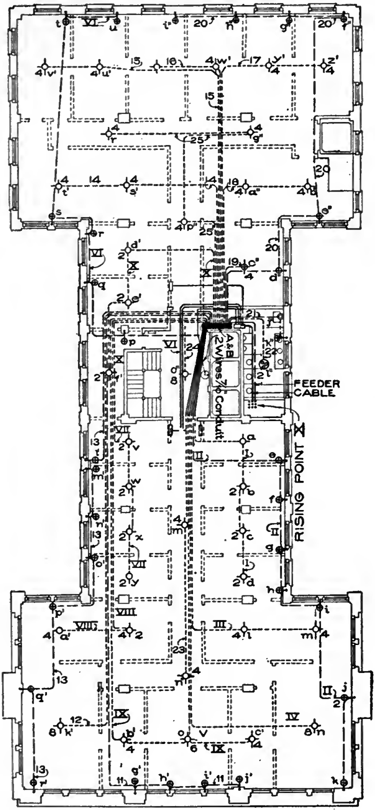
TERMINATE ALL MOTOR CIRCUITS AT MOTOR CONTROLLER AS DIRECTED

MOTOR CIRCUITS

NO.	SUPPLIED BY FEEDER NO.	SUPPLIED BY CUT-OUT	SUPPLIED BY FLOOR	H.P. SUPPLIED	CURRENT IN AMPERES	LENGTH IN FT. (ONE WAY)	SIZE OF WIRE	INSIDE DIA. OF CONDUIT ALLOWED *
12	9	D	2ND	* *		98	10	5/8"
13	"	"	"	"		90	"	"
14	"	"	"	"		82	"	"
15	"	"	"	"		76	"	"
16	"	"	"	"		68	"	"
17	"	"	"	"		60	"	"
18	"	"	"	"		52	"	"
19	"	"	"	"		46	"	"
20	"	"	"	"		38	"	"
21	"	"	"	"		28	"	"
22	"	"	"	"		94	"	"
23	"	"	"	"		86	"	"
24	"	"	"	"		78	"	"
25	"	"	"	"		70	"	"
26	"	"	"	"		62	"	"
27	"	"	"	"		54	"	"
28	"	"	"	"		46	"	"
29	"	"	"	"		38	"	"
30	"	"	"	"		30	"	"
31	"	"	"	"		90	"	"
32	"	"	"	"		"	"	"
33	"	"	"	$\frac{1}{4}$		82	"	"
34	"	E	"	3		28	"	"
35	"	"	"	"		32	"	"
36	"	"	"	"		52	"	"
37	"	"	"	"		34	"	"
38	"	"	"	1		48	12	"
39	"	"	"	2		46	10	"
40	"	"	"	3		30	"	"
41	"	"	"	2		28	"	"
42	"	"	"	3		18	"	"

* BOTH CONDUCTORS IN ONE CONDUIT
** $\frac{1}{2}$ H.P. REDUCED TO $\frac{1}{4}$ H.P.

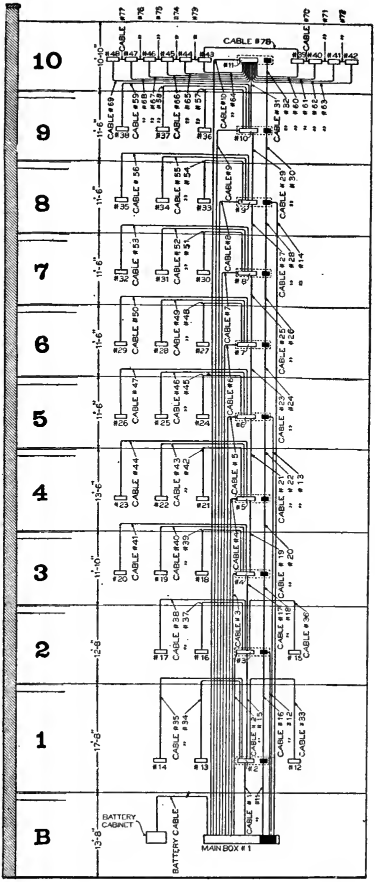
Fig. 44. Wiring of an Office Building. Plan of Second Floor. Rear Portion Occupied as a Composing and Linotype Room.



SCHEDULE OF CIRCUITS

NO.	SUPPLIED by CUTOUT	SUPPLIED by MAIN	No. of BRANCHES	OUTLETS SUPPLIED	TOTAL OUTLETS	TOTAL LIGHTS	AT WHAT POINT CONTROLLED
I	A		1	abcd	4	8	
II	"	"	1	efghijk	7	7	
III	"	"	1	lm	2	8	
IV	"	"	1	n	1	8	
V	"	"	1	o	1	6	
VI	"	"	1	pqrstu	6	6	
VII	"	"	1	vwxy	4	8	
VIII	"	"	1	z a'	2	8	
IX	"	"	1	b'c'	2	8	
X	"	"	1	d'e'f'	3	6	
11	"	"	1	g'h'i'j'	4	4	
12	"	"	1	k'	1	8	
13	"	"	1	l'm'n'o'p'q'r'	7	7	
14	"	"	1	s't'	2	8	
15	"	"	1	u'v'	2	8	
16	"	"	1	w'x'	2	8	
17	"	"	1	y'z'	2	8	
18	"	"	1	a"b"	2	8	
19	"	"	1	c"	1	4	
20	"	"	1	d"e"f"g"h"i"	6	6	
21	"	"	1	j"k"	2	2	
22	"	"	1	l"	1	2	S at A
					64	146	
23	B		1	m"n"	2	8	S at B
24	"	"	1	o"	1	8	S " "
25	"	"	1	p"q"r"	3	12	S " "
					6	28	

Fig. 45. Wiring of an Office Building.
Typical Plan of Upper Floors, Showing Circuit Work, Schedule, etc. All the Floors above the Second are Similar to One Another in Plan, Differing Only in Comparatively Unimportant Details of Partitions.



— CABLES. —

NO.	START AT BOX NO.	START AT FLOOR	END AT BOX NO.	END AT FLOOR	NO. OF WIRES	LENGTH IN FEET	INSIDE DIA. of CONDUIT ALLOWED
1	1	BAS'M'T	2	1 ST	50	122	1½"
2	"	"	3	2 ND	"	116	"
3	"	"	4	3 RD	"	128	"
4	"	"	5	4 TH	"	139	"
5	"	"	6	5 TH	"	154	"
6	"	"	7	6 TH	"	165	"
7	"	"	8	7 TH	"	176	"
8	"	"	9	8 TH	"	187	"
9	"	"	10	9 TH	"	208	"
10	"	"	11	10 TH	"	219	"
11	"	"	2	1 ST	10	122	"
12	"	"	3	2 ND	"	116	"
13	"	"	6	5 TH	"	154	"
14	"	"	9	8 TH	"	187	"
15	2	1 ST	3	2 ND	"	22	1"
16	"	"	"	"	"	"	1½"
17	3	2 ND	4	3 RD	"	16	1"
18	"	"	"	"	"	"	1½"
19	4	3 RD	5	4 TH	"	15	1"
20	"	"	"	"	"	"	1½"
21	5	4 TH	6	5 TH	"	"	1"
22	"	"	"	"	"	"	1½"
23	6	5 TH	7	6 TH	"	"	1"
24	"	"	"	"	"	"	1½"
25	7	6 TH	8	7 TH	"	"	1"
26	"	"	"	"	"	"	1½"
27	8	7 TH	9	8 TH	"	"	1"
28	"	"	"	"	"	"	1½"
29	9	8 TH	10	9 TH	"	"	1"
30	"	"	"	"	"	"	1½"
31	10	9 TH	11	10 TH	"	"	1"
32	"	"	"	"	"	"	1½"
33	2	1 ST	12	1 ST	"	61	1"
34	"	"	13	"	"	22	"
35	"	"	14	"	"	84	"
36	3	2 ND	15	2 ND	"	55	"
37	"	"	16	"	"	28	"
38	"	"	17	"	"	22	"
39	4	3 RD	18	3 RD	"	25	"
40	"	"	19	"	"	53	"
41	"	"	20	"	"	51	"
42	5	4 TH	21	4 TH	"	25	"
43	"	"	22	"	"	53	"
44	"	"	23	"	"	51	"
45	6	5 TH	24	5 TH	"	25	"
46	"	"	25	"	25	53	1½"
47	"	"	26	"	10	51	1"
48	7	6 TH	27	6 TH	"	25	"
49	"	"	28	"	"	53	"
50	"	"	29	"	"	51	"
51	8	7 TH	30	7 TH	"	25	"
52	"	"	31	"	"	53	"
53	"	"	32	"	"	51	"
54	9	8 TH	33	8 TH	"	25	"
55	"	"	34	"	"	53	"
56	"	"	35	"	"	51	"
57	10	9 TH	36	9 TH	"	25	"
58	"	"	37	"	"	53	"
59	"	"	38	"	"	51	"
60	11	10 TH	39	10 TH	"	29	"
61	"	"	49	"	"	36	"
62	"	"	41	"	"	31	"
63	"	"	42	"	"	39	"
64	"	"	43	"	"	40	"
65	"	"	44	"	"	58	"
66	"	"	45	"	"	79	"
67	"	"	46	"	"	93	"
68	"	"	47	"	"	75	"
69	"	"	48	"	"	56	"
70	39	"	49	"	*	11	"
71	49	"	41	"	"	18	"
72	41	"	42	"	"	13	"
73	43	"	44	"	"	33	"
74	44	"	45	"	"	22	"
75	45	"	46	"	"	"	"
76	46	"	47	"	"	"	"
77	47	"	48	"	"	"	"
78	39	"	43	"	"	"	"

* EMPTY CONDUIT ONLY

— BOXES. —

NO.	FLOOR	NO. REQUIRED OF VARIOUS SIZES: 60 F	1-A	14-B	16-B	20-8	2-8	3-A				
1	BAS'M'T	1										
2	1 ST			1								
3	2 ND				1							
4	3 RD			1								
5	4 TH			1								
6	5 TH				1							
7	6 TH			1								
8	7 TH			1								
9	8 TH				1							
10	9 TH			1								
11	10 TH					1						
12	1 ST						1					
13	"						1					
14	"						1					
15	2 ND						1					
16	"						1					
17	"						1					
18	3 RD						1					
19	"						1					
20	"						1					
21	4 TH						1					
22	"						1					
23	"						1					
24	5 TH						1					
25	"						1					
26	"						1					
27	6 TH						1					
28	"						1					
29	"						1					
30	7 TH						1					
31	"						1					
32	"						1					
33	8 TH						1					
34	"						1					
35	"						1					
36	9 TH						1					
37	"						1					
38	"						1					
39	10 TH		1									
40	"		1									
41	"		1									
42	"		1									
43	"		1									
44	"		1									
45	"		1									
46	"							1				
47	"		1									
48	"		1									
TOTALS		1	9	6	3	1	27	1				

— FIXTURES. —

LOCATION	BATTERIES	BATTERY CABINET	CLOCKS	MASTER CLOCK								
BASEMENT	28	1										
1 ST FL.			4									
2 ND "			2									
3 RD "			1									
4 TH "			1									
5 TH "			1									
6 TH "			1									
7 TH "			1									
8 TH "			1									
9 TH "			1									
10 TH "			3	1								
				1								
TOTALS	28	1	16	1								

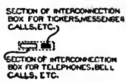


Fig. 46. Wiring of an Office Building. Diagram of the Interconnection System.

basement; adjoining this main box is located the terminal box of the local telephone company. A separate system of feeders is provided for the ticker system, as these conductors require somewhat heavier insulation, and it was thought inadvisable to place them in the same conduits with the telephone wires, owing to the higher potential of ticker circuits. A separate interconnection cable runs to each floor, for telephone and messenger call purposes; and a central box is placed near the rising point at each floor, from which run subsidiary cables to several points symmetrically located on the various floors. From these subsidiary boxes, wires can be run to the various offices requiring telephone or other service. Small pipes are provided to serve as raceways from office to office, so as to avoid cutting partitions. In this way, wires can be quickly provided for any office in the building without damaging the building in any way whatever; and, as provision is made for a special wooden moulding near the ceiling to accommodate these wires, they can be run around the room without disfiguring the walls. All the main cables and subsidiary wires are connected with special interconnection blocks numbered serially; and a schedule is provided in the main interconnection box in the basement, which enables any wire originating thereat, to be readily and conveniently traced throughout the building. All the main cables and subsidiary cables are run in iron conduits.

OUTLET-BOXES, CUT-OUT PANELS, AND OTHER ACCESSORIES

Outlet-Boxes. Before the introduction of iron conduits, outlet-boxes were considered unnecessary, and with a few exceptions were not used, the conduits being brought to the outlet and cut off after the walls and ceilings were plastered. With the introduction of iron conduits, however, the necessity for outlet-boxes was realized; and the *Rules* of the Fire Underwriters were modified so as to require their use. The *Rules of the National Electric Code* now require outlet-boxes to be used with rigid iron and flexible steel conduits, and with armored cables. A portion of the rule requiring their use is as follows:

All interior conduits and armored cables "must be equipped at every outlet with an approved outlet-box or plate.

"Outlet-plates must not be used where it is practicable to install outlet-boxes.

"In buildings already constructed, where the conditions are such that neither outlet-box nor plate can be installed, these appliances may be omitted by special permission of the inspection department having jurisdiction, providing the conduit ends are bushed and secured."

Fig. 47 shows a typical form of outlet-box for bracket or ceiling outlets of the *universal type*. When it is desired to make an opening for the conduits, a blow from a hammer will remove any of the weakened portion of the wall of the outlet-box, as may be required. This form of outlet-box is frequently referred to as the *knock-out type*. Other forms of outlet-boxes are made with the openings cast in the box at the required points, this class being usually stronger and better made than the universal type. The advantages of the universal type of outlet-box are that one form of box will serve for any ordinary conditions, the openings being made according to the number of conduits and the directions in which they enter the box.

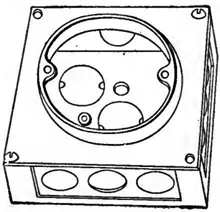


Fig. 47. Universal and Knock-Out Type of Outlet Box.

Fig. 48 shows a waterproof form of outlet-box used out of doors, or in other places where the conditions require the use of a water-tight and waterproof outlet-box.

It will be seen in this case, that the box is threaded for the conduits, and that the cover is screwed on tightly and a flange provided for a rubber gasket.

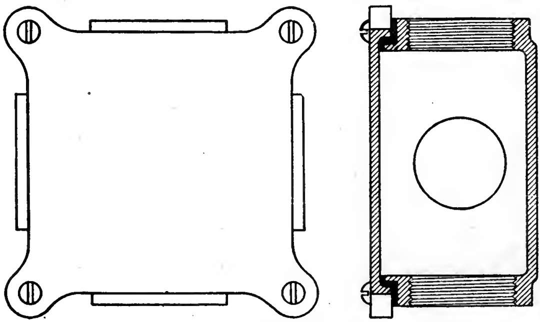


Fig. 48. Water-Tight Outlet Box.
Courtesy of H. Krantz Manufacturing Co., Brooklyn, N. Y.

Figs. 49 and 50 show water-tight floor boxes which are for outlets located in the floor. While the rules do not require that the floor outlet-box shall be water-tight, it is strongly recommended that a water-tight outlet be used in all cases for floor connections. In this case also, the conduit opening is threaded, as well as the stem cover through which the extension is made in the conduit to the desk or table. When the floor outlet connection is not required, the stem cover may be removed and a flat, blank cover be used to replace the same.

A form of outlet-box used for flexible steel cables and steel armored cable, has already been shown (see Fig. 5).

There is hardly any limit to the number and variety of makes of outlet-boxes on the market, adapted for ordinary and for special con-

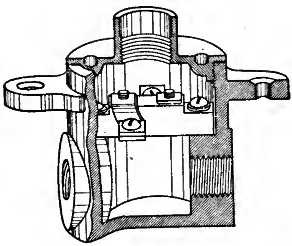


Fig. 49.

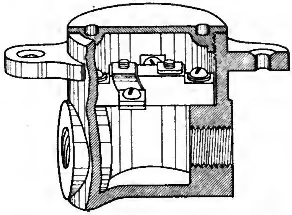


Fig. 50.

Types of Floor Outlet-Boxes.

ditions; but the types illustrated in these pages are characteristic and typical forms.

Bushings. The *Rules of the National Electric Code* require that conduits entering junction-boxes, outlet-boxes, or cut-out cabinets shall be provided with approved *bushings,* fitted to protect the wire from abrasion.

Fig. 51 shows a typical form of conduit bushing. This bushing is screwed on the end of the conduit after the latter has been introduced into the outlet-box, cut-out cabinet, etc., thereby forming an insulated orifice to protect the wire at the point where it leaves the conduits, and to prevent abrasion, grounds, short circuits, etc. A lock-nut (Fig. 52) is screwed on the threaded end of the conduit before the conduit is placed in the outlet-box or cut-out cabinet, and this lock-nut and bushing clamp the conduit securely in position. Fig.

53 shows a terminal bushing for panel-boxes used for flexible steel conduit or armored cable.

The *Rules of the National Electric Code* require that the metal of conduits shall be permanently and effectually grounded, so as to insure a positive connection for grounds or leaking currents, and in order to provide a path of least resistance to prevent the current from finding a path through any source which might cause a fire. At outlet-boxes, the conduits and gaspipes must be fastened in such a manner as to insure good electrical connection; and at centers of distribution, the conduits should be joined by suitable bond wires, preferably of copper, the said bond wires being connected to the metal structure of the building, or, in case of a building not having an iron or steel structure, being grounded in a permanent manner to water or gas piping.

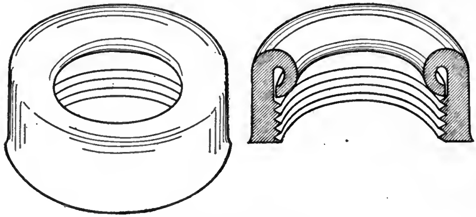


Fig. 51. Conduit Bushing.

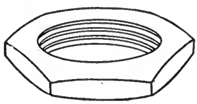


Fig. 52. Lock-Nut.

Fuse-Boxes, Cut-Out Panels, etc. From the very outset, the necessity was apparent of having a protective device in circuit with the conductor to protect it from overload, short circuits, etc. For this purpose, a fusible metal having a low melting point was employed. The form of this fuse has varied greatly. Fig. 54 shows a characteristic form of what is known as the *link fuse* with copper terminals, on which are stamped the capacity of the fuse.

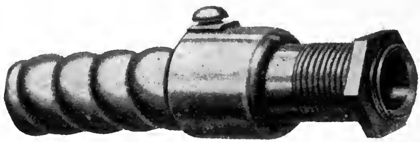


Fig. 53. Panel-Box Terminal Bushing.
Courtesy of Sprague Electric Co., New York, N. Y.

The form of fuse used probably to a greater extent than any other, although it is now being superseded by other more modern forms,

is that known as the *Edison fuse-plug,* shown in Fig. 55. A porcelain *cut-out block* used with the Edison fuse is shown in Fig. 56.

Within the last four or five years, a new form of fuse, known as the *enclosed fuse,* has been introduced and used to a considerable

Fig. 54. Copper-Tipped Fuse Link.

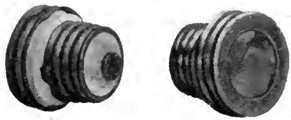


Fig. 55. Edison Fuse-Plug,
Courtesy of General Electric Co., Schenectady, N. Y.

extent. A fuse of this type is shown in Fig. 57. Fig. 58 gives a sectional view of this fuse, showing the porous filling surrounding the fuse-strips, and also the device for indicating when the fuse has blown. This form of fuse is made with various kinds of terminals; it can be used with spring clips in small sizes, and with a post screw contact in larger sizes. For ordinary low potentials this fuse is desirable for currents up to 25 amperes; but it is a debatable question whether it is desirable to use an enclosed fuse for heavier currents. Fig. 59 shows a *cut-out box* with Edison plug fuse-blocks used with knob and tube wiring. It will be seen that there is no connection compartment in this fuse-box, as the circuits enter directly opposite the terminals with which they connect.

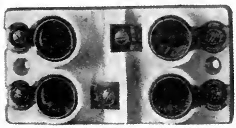


Fig. 56. Porcelain Cut-Out Block.
Courtesy of General Electric Co., Schenectady, N. Y.

Fig. 60 shows a *cut-out panel* adapted for enclosed fuses, and installed in a cabinet having a connection compartment. As will be seen from the cut, the tablet itself is surrounded on the four sides by slate, which is secured in the corners by angle-irons. The outer box may be of wood lined with sheet iron, or it may be of iron. Fig. 61 shows a door and trim for a cabinet of this type. It will be seen that

Fig. 57. Enclosed or "Cartridge" Fuse.

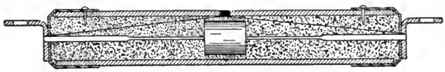


Fig. 58. Section of Enclosed Fuse.

the door opens only on the center panel, and that the trim covers and conceals the connection compartment. The inner side of the door should be lined with slate, and the inner side of the trim should be lined with sheet iron. Fig. 62 shows a sectional view of the cabinet and panel. In this type of cabinet, the conduits may enter at any point, the wires being run to the proper connectors in the connection compartment.

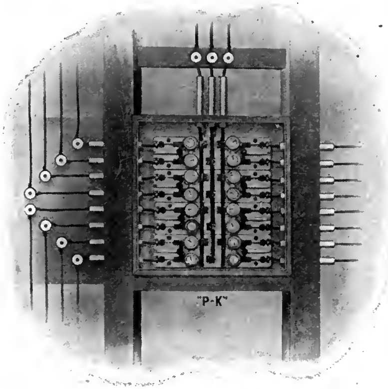


Fig. 59. Porcelain Cut-Outs in Wooden Box.
Courtesy of H. T. Paiste Co., Philadelphia, Pa.

Figs. 63 and 64 illustrate a type of panel-board and cabinet having a push-button switch connected with each branch circuit and so arranged that the cut-out panel itself may be enclosed by locked doors, and access to the switches may be obtained through two separate doors provided with latches only. This type of panel was arranged and designed by the author of this instruction paper.

OVERHEAD LINEWORK

The advantages of overhead linework as compared with underground linework are that it is much less expensive; it is more readily and more quickly installed; and it can be more readily inspected and repaired.

Its principal disadvantages are that it is not so permanent as underground linework; it is more easily deranged; and it is more unsightly.

For large cities, and in congested districts, overhead linework should not be used. However, the question of first cost, the question of permanence, and the municipal regulations, are usually the factors which determine whether overhead or underground linework shall be used.

The principal factors to be considered in overhead linework will be briefly outlined.

Placing of Poles. As a general rule, the poles should be set from 100 to 125 feet apart, which is equivalent to 53 to 42 poles per mile. Under certain conditions, these spacings given will have to be modified; but if the poles are spaced too far apart, there is danger of too great a strain on the poles themselves, and on the cross-arms, pins, and

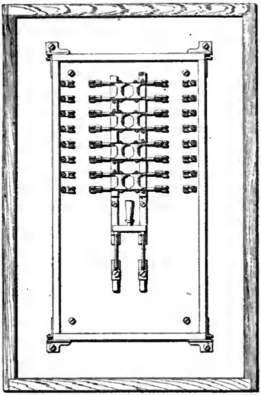


Fig. 60. Plan View, Cover, and Section of Double Cut-Out Box.

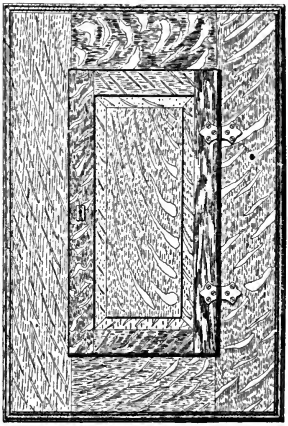


Fig. 61.

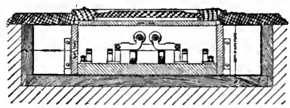


Fig. 62.

conductors. If, on the other hand, they are placed too close together, the cost is unnecessarily increased. The size and number of conductors, and the potential of the linework, determine to a great extent the distance between the poles; the smaller the size, the less the number of conductors; and the lower the potential, the greater the distance between the poles may be made. Of course, the exact location of the poles is subject to variation because of trees, buildings, or other obstructions. The usual method employed in locating poles, is first to make a map on a fairly large scale, showing the course of the linework, and then to locate the poles on the ground according tc the actual conditions.

Poles. Poles should be of selected quality of chestnut or cedar, and should be sound and free from cracks, knots, or other flaws. Experience has proven that chestnut and cedar poles are the most durable and best fitted for linework. If neither chestnut nor cedar poles can be obtained, northern pine may be used, and even other timber in localities where these poles cannot be obtained; but it is found that the other woods do not last so long as those mentioned,

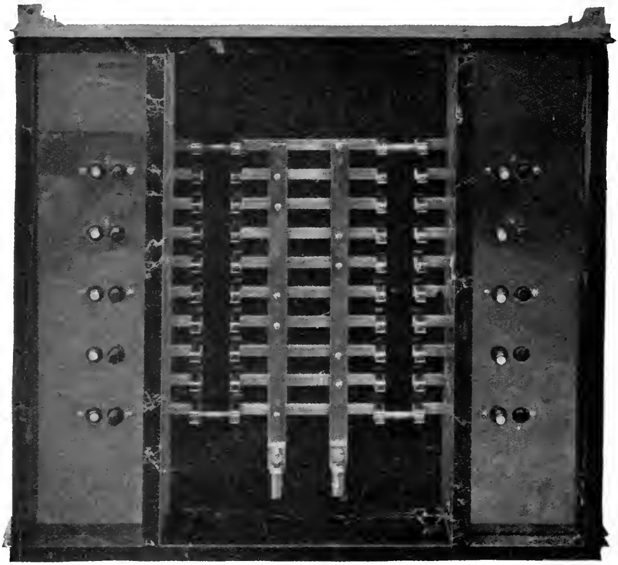


Fig. 63. Cut-Out Panel with Push-Button Switches. Cover Removed.

and some of the other woods are not only less strong initially, but are apt to rot much quicker at the "wind and water line"—that is, just above and below the surface of the ground.

The proper height of pole to be used depends upon conditions. In country and suburban districts, a pole of 25 to 30 feet is usually of sufficient height, unless there are more than two or three cross-arms required. In more densely populated districts and in cities where a great number of cross-arms are required, the poles may have to be

40 to 60 feet, or even longer. Of course, the longer the pole, the greater the possibility of its breaking or bending; and as the length increases, the diameter of the butt end of pole should also increase. Table X gives the average diameters required for various heights of poles, and the depth the poles should be placed in the ground. These data have been compiled from a number of standard specifications.

TABLE X

Pole Data

Length of Pole	Diameter 6 In. from Butt	Diameter at Top	Depth Pole should be Placed in Ground
25 feet	9 to 10 in.	6 to 8 in.	5 feet
30 "	11 "	"	5½ "
35 "	12 "	"	5½ "
40 "	13 "	"	6 "
45 "	14 "	"	6½ "
50 "	15 "	"	7 "
55 "	16 to 17 "	"	7½ "
60 "	18 "	"	7½ "
65 "	19 "	"	8 "
70 "	20 "	"	8 "
75 "	21 "	"	8½ "
80 "	22 "	"	9 "

As it is somewhat difficult, because of irregularities in size, to measure the diameter of some poles, the circumference may be measured instead; then, by multiplying the diameters given in the above table, by 3,1416, the measurements may be reduced to the circumference in inches.

The minimum diameters of the pole at the top, which should be allowed, will depend largely on the size of the conductors used, and on the potential carried by the circuits; the larger the conductors and the higher the potentials, the greater should be the diameter at the top of the pole.

Poles should be shaved, housed, and gained, also cleaned and ready for painting, before erection.

Poles should usually be painted, not only for the sake of appearance, but also in order to preserve them from the weather. It is particularly important that they should be protected at their butt end, not only where they are surrounded by the ground, but for a foot or two above the ground, as it is at this point that poles usually deteriorate most rapidly. Painting is not so satisfactory at this point as the use of tar, pitch, or creosote. The life of the pole can be increased considerably by treating it with one or another of these preservatives.

Before any poles are erected, they should be closely inspected for flaws and for crookedness or too great departure from a straight line.

Where appearance is of considerable importance, octagonal poles may be used, although these cost considerably more than round poles. *Gains* or notches for the cross-arms should be cut in the poles before they are erected, and should be cut square with the axis of the pole, and so that the cross-arms will fit snugly and tightly within the space thus provided. These gains should be not less than 4½ inches wide,

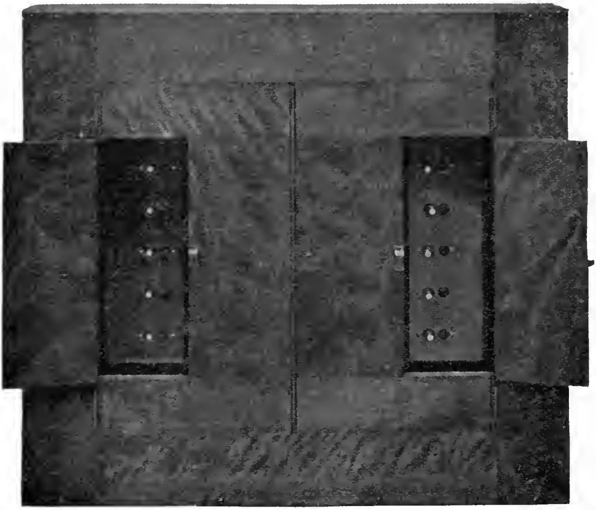


Fig. 64. Cut-Out Panel with Push-Button Switches. With Cover.

nor less than ½ inch deep. Gains should not be placed closer than 24 inches between centers, and the top gains should be at least 9 inches from the apex of the pole.

Pole Guying. Where poles are subject to peculiar strains due to unusual stress of the wires, such as at corners, etc., *guys* should be employed to counteract the strain and to prevent the pole from being bent and finally broken, or from being pulled from its proper position.

Where there are a considerable number of wires on the poles, or in case of unusually long poles, or where the linework is subject to severe storms, it is frequently necessary to guy the poles even on straight linework. In such cases, the guys should extend from a point near the top of the pole to a point near the butt of the adjacent pole. Straight guying should also be employed at the terminal pole, the guy extending to a stub beyond the last pole, to counteract the strain of the wires pulling in the opposite direction. On particularly heavy lines, it is sometimes necessary to use straight guys for the second and even the third pole from the terminal pole, to prevent undue strain on the terminal pole itself, as shown in Fig. 65.

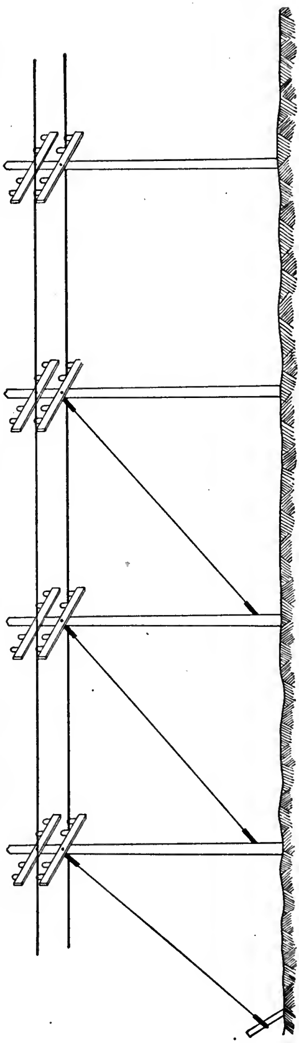


Fig. 65. Use of Straight Guys on Poles at Terminus of Heavy Line.

Where there are three or more cross-arms, either two sets of guys should be employed, or else a "Y" form of guy should be used. If a single guy is used on a long pole or on a pole carrying a number of cross-arms, or on which there is unusual strain, the pole is apt to break where the guy is attached. Figs. 66 and 67 show respectively a proper and an improper method of guying, and their effect.

At corners, or wherever the direction of the linework changes, guys should be provided to counteract the strain due to the change in direction. Guys are also necessary at points where poles are set in other than a vertical position.

Where the soil is not firm or solid, or where poles are subject to unusual stress, it is sometimes necessary to obtain additional stiffness by what is known as *crib-bracing*, as may be seen from Fig. 68. This consists of placing two short logs at the butt of the pole. These logs need not be more than 4 to 5 feet long, or more than 8 to 9 inches

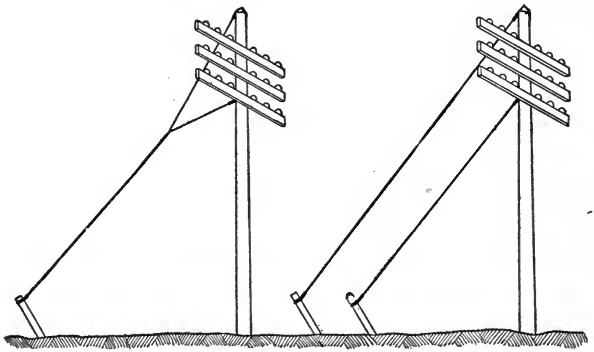


Fig. 66. Proper Method of Guying where there are Three or More Cross-Arms. A Y-form of Guy is Used at Left; Double Guy at Right.

in diameter. This crib-bracing is sometimes also necessary to give greater stability to stubs or short poles to which guys are fastened.

While, as a rule, it is not advisable to use trees for guy supports, it is sometimes necessary to do this, but the trees should be sound and should be protected in a proper manner from injury. On private property, permission should first be obtained from the owner to use the tree for such purpose.

The guy itself should be of standard cable, consisting of 7 strands of No. 12 B. & S. Gauge iron or steel wire. This is the standard *guy cable*, and should be used in all cases, except for very light poles and light linework, where a smaller cable having a minimum diameter of $\frac{1}{4}$ inch may be used. The guy wires should be fastened at the ends by means of suitable clamps. All guy cables and clamps should be heavily galvanized, to prevent rusting.

Corners. In cases of heavy linework where there are a considerable number of wires and cross-arms, the turns should be made,

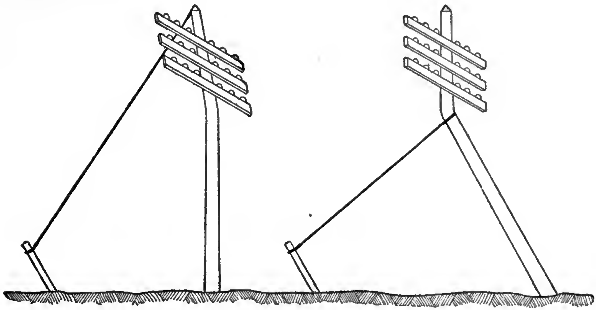


Fig. 67. Improper Method of Guying where there are Three or More Cross-Arms. Strain is Concentrated at one Point, Causing Rupture of Pole.

if possible, by the use of two poles. In cases where there are only a few wires, a double cross-arm may be employed, using a single pole. The two methods are illustrated in Figs. 69 and 70.

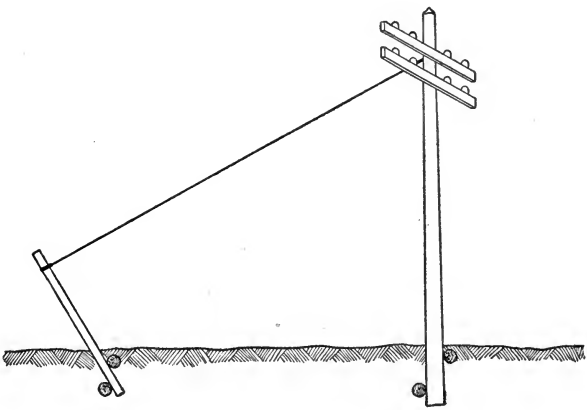


Fig. 68. Additional Stiffness Secured by Use of Crib-Bracing.

Cross-Arms. Cross-arms, where possible, should be of long leaf yellow pine, or of Oregon or Washington fir, of sound wood,

thoroughly seasoned and free from sap, cracks, or large knots. They should be not less than $3\frac{1}{4}$ inches thick by $4\frac{1}{4}$ inches deep, the length depending upon the number of pins required.

Cross-arms, after being properly seasoned, should be painted with two coats of lead paint before erection. They should then be snugly fitted into the gain of the pole, and securely fastened with a bolt not less than $\frac{5}{8}$ inch in diameter driven through a hole of slightly less diameter previously bored in the pole. A galvanized-iron washer not less than 2 inches in diameter should be placed under the head and nut of each bolt. The cross-arms should be at right angles to the pole, and should be parallel to one another where two or more arms are used on the same pole.

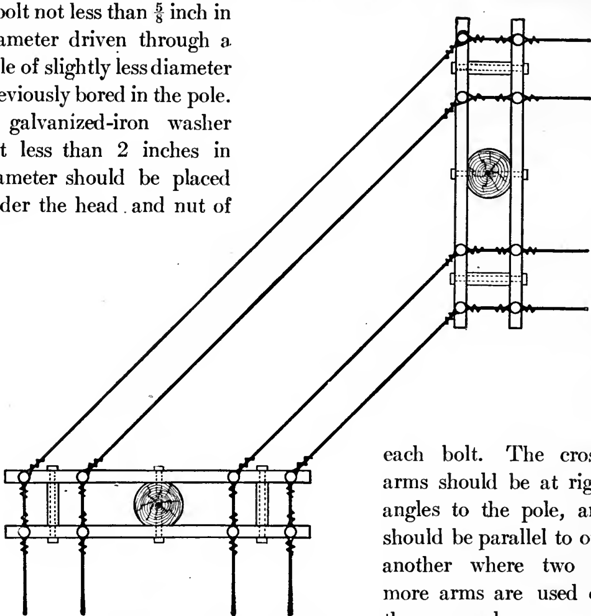


Fig. 69. Two-Poles Used in Making Turn on Heavy Line.

The cross-arms should be braced with galvanized-iron *braces* approximately $1\frac{1}{4}$ inches wide, $\frac{1}{4}$ inch thick, and from 18 to 30 inches in length. The braces should be fastened to the cross-arm by means of $\frac{3}{8}$-inch galvanized-iron bolts passing through the brace and the cross-arm, washers being used under the nut and head of each bolt. Guys should be provided for the cross-arms in case of unusual strain. The dimensions of cross-arms required for various numbers of pins, are given verv completely in a

paper read by Mr. Paul Spencer before the Atlantic City Convention of the National Electric Light Association in 1906, and reprinted in a number of the technical journals.

Wherever practicable, cross-arms should be placed on the poles before the poles are erected, as not only can they be more securely fastened when the poles are on the ground, but the cost of erection is thereby considerably reduced.

Pins. Pins should be of selected locust, not less than 1½ inches in diameter at the shank portion, and not less than ¾ inch in diameter at the point where they rest upon the cross-arm. For potentials of 20,000 volts or over, the pins should be of metal, to avoid carbonization of the wood due to static leakage. The top portion of the pin (if of wood) should be not less than one inch in diameter. The length of both the shank and the upper portion should be each approximately 4½ inches, making the total length approximately 9 inches. The pin should be threaded and tapered, and accurately cut. The pin should fit the hole in the cross-arm snugly, and should be nailed to the cross-arm with a sixpenny galvanized-iron wire nail driven straight through the center of the shank of the pin.

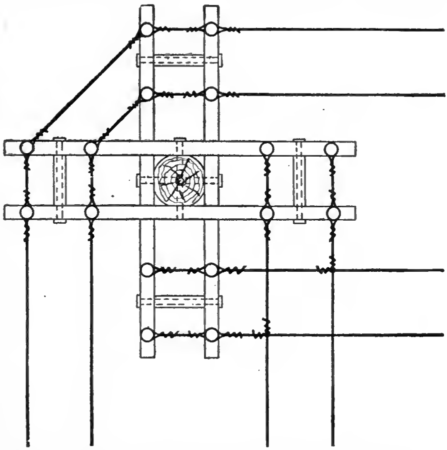


Fig. 70. Double Cross-Arm Used on Single Pole to Make Turn in Heavy Line Carrying Only a Few Wires.

Insulators. For potentials of 3,000 volts or less, insulators should be of flint glass, of double-petticoat, deep-grooved type. For potentials of over 3,000 volts, they should be of the triple-petticoat type, and preferably of porcelain, and should be of special pattern adapted for the potential.

Service Mains, Pole Wiring, etc. For service connections—

that is, for the mains run to service switches in consumers' residences or other buildings, conductors of not less than No. 8 B. & S. Gauge should be used in order to obtain the necessary tensile strength. Where possible, the circuits should be arranged in such a manner as to have the service main connect with the line on the lowest cross-arm, in order to prevent crossing of wires. The transformers should be installed either on poles or in vaults outside of the building, or, where this is impracticable, in a fireproof vault or other enclosed space inside of the building itself. Small transformers may be fastened to a pair of cross-arms secured to the pole itself. For transformers of 25 K.W. and over, it is usually best to provide special poles. It is inadvisable to place transformers on building walls.

Where appearance is of importance, when the transformer is placed underground, or when the wires enter the lower portion of a building, the conductors must be run underground. In such cases, a splice should be made between the weatherproof conductors and rubber-insulated lead-sheathed conductors, at a height of about 15 to 20 feet above the ground, and the mains run in iron pipe down the pole to a point underground, where they may be continued either in iron pipe or in vitrified or fiber conduits underground to the point of entrance.

All circuit wiring on poles should be so arranged as to leave one side free for the linemen to climb the poles without injuring the conductors. As a rule, all poles on which transformers, lightning arresters, or fuse-boxes are located, should be provided with steps.

In order to limit the area of disturbance of a short circuit or overload, fuses should be inserted in each leg of a primary circuit in making connections to transformers, or where tap or branch connections are made. The fuses should have a capacity of approximately 50 per cent greater than the transformer or conductor which they protect. Of course, it would be undesirable to have an excessive number of fuses, and for short branch lines they might frequently be undesirable; but for important branch lines, they should be employed in order to prevent the fuse on the main feeder from being *blown* in case of disturbance on the branch line.

Lightning arresters should be placed on the linework in places particularly exposed to lightning discharges, and at all points where connections are made to enter a building. The location and number

of lightning arresters will depend upon local conditions, the likelihood and frequency of thunderstorms, etc. Where lightning arresters are provided, it is essential that a good ground connection be obtained. The ground connection should be made by a fairly good-sized insulated rubber conductor, not less than No. 6 B. & S. Gauge, connecting either with a water pipe to which it should be clamped, or fastened in such a manner as to obtain a good electric contact, or else to a ground-plate of copper embedded in crushed charcoal or coke.

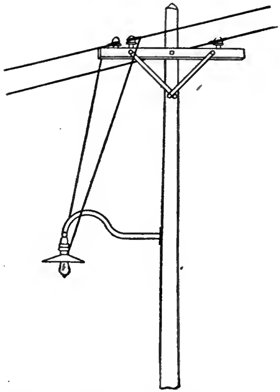


Fig. 71. Method of Wiring to and Supporting Lamp on Pole.

The neutral wire of a three-wire of both secondary alternating-current systems and direct-current systems, should be properly grounded as required by the *National Electric Code* (see Rules 12, 13, and 13-A).

Lamps on Poles. Fig. 71 shows the method of wiring to and supporting a lamp located on a pole.

UNDERGROUND LINEWORK

In large cities, or in congested districts, or where the appearance of overhead linework is objectionable, it is generally necessary to place the conductors underground instead of overhead.

The advantages of underground linework are—*first*, that of appearance; *second*, it is more permanent and less liable to interruption than overhead work.

The principal disadvantage of underground work is the greater first cost. In overhead linework, conductors having weatherproof insulators consisting of cotton dipped in a special compound similar to pitch, are used, the cost of which is relatively small. For underground linework, however, the conductors must not only have rubber insulation, but also a lead sheathing for mechanical protection.

Furthermore, the cost of the ducts, trenching, concrete work, laying the ducts, etc., is much greater than the cost of poles, cross-arms, etc.

As in the case of inside wiring, underground linework should be so arranged that the conductors may be readily removed and replaced without disturbing the underground conduits or ducts. The system should be arranged with *manholes,* and in such a manner that changes or additions or branches may be readily and conveniently made. In order to provide for the removal and replacing of conductors, and also for growth in the system, the method formerly in vogue, of embedding the conductors in wooden boxes, or in trenches underground, has been abandoned; and the conductors are now placed in *conduits* or *ducts.* A number of different forms of ducts and conduits have been introduced, some of which have been dropped as cheaper and better forms have been introduced. The forms of conduits or ducts now most generally employed include *iron pipe, vitrified conduits,* and *fibre conduit.* As all three of these forms of conduit are very generally employed, they will now be described, as well as the method of installing them.

Iron Pipe. Three-inch iron conduit is frequently used for underground linework, particularly for short runs or where there are not more than two or three ducts required, or where the soil is bad and where the longer lengths and more stable joints of the iron conduit would make it more desirable than vitrified duct or fibre conduit. This conduit, however, is generally undesirable on account of its greater first cost, and also on account of its liability to deterioration from rust or corrosion. Where iron conduit is used, and where it is subject to corrosion, it should be coated with asphaltum or other similar protective composition. While it is not necessary to have a concrete bed under iron pipe, it is better to provide such a bed, especially where the soil is shifting or not solid.

Vitrified Tile Conduit. This type of conduit in both the single- and multiple-duct form, is used more extensively than any other form of conduit for underground work. It is made in lengths of 18 inches for the single-duct form, and in considerably greater lengths in the multiple-duct form. Fig. 72 shows the single-duct conduit, and Fig. 73 shows a multiple-duct form of conduit.

Vitrified conduit requires less space for the same number of ducts than any other form. and is particularly desirable where a great

number of ducts are required in a small space. The advantages of this form of conduit are that it is cheap in first cost; after being laid, it is practically indestructible; it is not subject to corrosion or

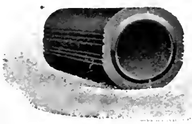


Fig. 72. Self-Centering Duct, Vitrified Conduit.
Courtesy of Standard Vitrified Conduit Co., New York, N. Y.

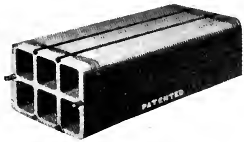


Fig. 73. Multiple Duct, Vitrified Conduit.
Courtesy of Standard Vitrified Conduit Co., New York, N. Y.

deterioration; it is not combustible; it is fairly strong mechanically; and it does not require skilled labor to install.

Table XI gives the principal data of one of the well-known makes of vitrified conduit.

TABLE XI
Standard Vitrified Conduit

Style of Conduit	Dimension of Square Duct (Inches)	Dimension of Round Duct (Inches)	Outside Dimensions of End Section (In.)	Reg. Stock Lengths (Inches)	Short Lengths (Inches)	Approx. Weight per Duct (Foot)
2-duct multiple...	3⅜ sq.	3¼	5 x 9	24	6, 9, 12	8 lbs.
3-duct multiple...	3⅜ sq.	3¼	5 x 13	24	6, 9, 12	8 "
4-duct multiple...	3⅜ sq.	3¼	9 x 9	36	6, 9, 12	8 "
6-duct multiple...	3⅜ sq.	3¼	9 x 13	36	6, 9, 12	8 "
9-duct multiple...	3⅜ sq.	3¼	13 x 13	36	6, 9, 12	8 "
Common single duct		3⅜	5 x 5	18	6, 9, 12	8 "
Single duct, self-centering......		3⅜	5 x 5	18	6, 9, 12	10 "
Round single duct, self-centering...		3¼	5 in. round	18	6, 9, 12	10 "

In installing vitrified conduit, a trench following as straight lines as possible should be dug to such a depth that there will be a space of at least 18 inches from the top layer of the duct to the street surface. The bottom of the trench should be level; and a bed of good cement concrete not less than 3 inches thick should be laid. The following instructions* for installing vitrified conduit may be considered as typical of the best up-to-date practice:

*From the Catalogue of the Standard Underground Conduit Company.

Laying of Conduit. When the trench has been properly prepared and the concrete foundation set, the laying of conduit should be begun. The ends of the conduit should be butted against the shoulder of the conduit terminal brick; short length should be used for the breaking of joints.

Care should be taken, when each length of conduit is laid, that the duct hole is perfectly clear and the conduit level. The work may then proceed; and if the following instructions are carried out, no difficulty will be encountered after the duct are laid.

When the first piece of conduit is laid and the keys inserted, one on the top and one on the side of the duct, the burlap for joints should be slipped partly under the conduit, and the next piece brought up and connected. The burlap is then brought up and wrapped around the conduit. After this operation is completed, a thin layer of cement mortar is plastered around the burlap, extending over the edges, so as to cover the scarified portion of the conduit so that it may adhere to it, thus making the joint practically water-tight.

The burlap should be first prepared in strips of not less than 6 inches in width, and of suitable length to wrap around the conduit, overlapping about 6 inches. If possible, the burlap should be saturated in asphaltum or pitch; but if this is not convenient, it may be dipped in water so as to stick to the conduit until the joint has been cemented. The engineer or foreman in charge should personally oversee the making of the joint, and especially see that the keys are inserted, as in many instances they are left out by the workmen, causing considerable trouble and expense. Sufficient time should be allowed for the joints to harden.

After the duct are laid, the sides are filled in with either concrete or dirt, as specified, care being taken that the conduit are not forced out of alignment by the careless filling-in of the sides. The top layer of concrete may then be laid and leveled.

After this the trench is ready for filling in.

In the laying of our self-centering single-duct conduit, no dowel-pins are used, the ducts being self-centering—one piece of conduit socketing into the other. Burlaping and cementing of joint is not necessary. Otherwise the instructions for the laying of multiple-duct should be followed. The use of a mandrel in laying self-centering conduit is superfluous.

As each section of the system—that is, from manhole to manhole—is completed, it should be rodded to insure the duct being clear. For this purpose wooden rods are employed, the rods being from 3 to 4 feet long by one inch in diameter and provided with brass couplings on the ends. The first rod is pushed into the duct chamber, the second one is then attached, and then the third and so on, until the first rod appears in the manhole at the opposite end.

A wooden mandrel about 10 inches long, made to conform to the shape of the duct, but about $\frac{1}{4}$ inch smaller in diameter, is attached to the last rod, and a galvanized-iron wire is then attached to the other end of the mandrel. The rods are drawn through the duct and uncoupled, until the mandrel has passed through the ducts. The wire is left remaining in the chamber, and secured in the manhole to prevent its being pulled out. The same operation is repeated until all the ducts are tested and wired. Should obstructions be met with and the mandrel bind, the location of the obstructions can readily be ascertained from the length of rod yet remaining in the duct, and can easily be removed. This method is far better than pulling the mandrel through as the ducts are laid, as in many cases the duct is obstructed or thrown out of alignment by the filling-in of the concrete or trench, and this would not be noticed until an attempt was made to draw the cable. The wire left in the duct is used in drawing the cables.

Fibre Conduit. This type of conduit consists of wood fibre formed into a tube over a mandrel under pressure. After the tube

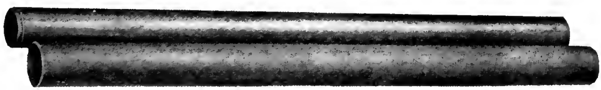


Fig. 74. Socket-Joint Fibre Conduit.

is formed on the mandrel, it is removed, and, after being dried in air, is placed in a tank of preservative and insulating compound.

Fibre conduits are made in three different styles—namely, the *socket-joint*, *sleeve-joint*, and *screw-joint* types, shown respectively in Figs. 74, 75, and 76. The forms of conduit here shown are made by the Fibre Conduit Company, of Orangeburg, New York.

In the socket-joint type, the connections between the lengths

of conduit are made by means of male and female joints turned on the ends of the conduit so that it is necessary only to push one length within the other to secure alignment without the use of a sleeve-coupling or other device. While this is the cheapest and simplest

Fig. 75. Sleeve-Joint Fibre Conduit.

form of fibre conduit, the joint is not so secure as in either of the other two types.

The sleeve-joint fibre conduit has the ends of each joint turned so that a sleeve may be slipped over the turned portion and butted up against the shoulder on the tubes. These sleeves are about 4 inches long and $\frac{3}{8}$ inch thick. While this form of joint is more secure than the socket type, it is not so secure as the screw-joint type.

The screw-joint type of fibre conduit is manufactured with a slightly thicker wall than the socket-joint type, in order to obtain the necessary thickness for getting the thread on the end of the pipe. The sleeve in this case is threaded; and, instead of being slipped on the conduit, as in the case of the sleeve-joint type, it is screwed on, and the thread may be filled with compound and a water-tight joint thereby obtained. Various special forms of elbows, bends, junction-boxes, tees, etc., are provided for this conduit, for special connections. Couplings are also made so that joints can be made between fibre conduit and iron pipe, where it is desirable to make such a connection.

The advantages of fibre conduit are—*first*, that it is lighter than any of the other forms of conduit, which reduces the cost of trans-

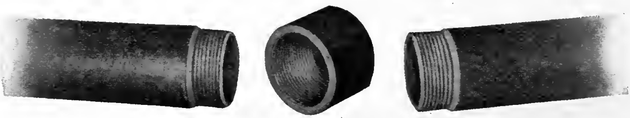


Fig. 76. Screw-Joint Fibre Conduit.

portation, carting, and handling; and *second*, that the cost of labor for installing it is less than in the case of iron pipe, and less than that of the single-duct tile pipe. Table XII gives the principal data relating to fibre conduit.

TABLE XII
Fibre Conduit

Inside Diameter (Inches)	Type of Conduit	Length (Feet)	Thickness of Wall (Inches)	Approx. Weight per Foot (lbs.)
1	Socket-joint	2-½	¼	0.50
1½	" "	5	¼	0.70
2	" "	5	¼	0.85
2½	" "	5	¼	1.02
3	" "	5	¼	1.20
3½	" "	5	¼	1.40
4	" "	5	¼	1.60
1½	Sleeve-joint	5	¼	0.80
2	" "	5	¼	0.95
2½	" "	5	¼	1.15
3	" "	5	7/16	2.40
3½	" "	5	7/16	2.90
4	" "	5	½	3.33
1½	Screw-joint	5	5/16	1.00
2	" "	5	⅜	1.45
2½	" "	5	⅜	1.75
3	" "	5	7/16	2.40
3½	" "	5	7/16	2.90
4	" "	5	½	3.33

Fig. 77 shows the method of laying fibre conduit in a trench.

A concrete bed should be provided for all three types of fibre conduit. Where the ground is moist or where there is likelihood of water getting in the joints, it is advisable to make a complete envelope around the conduit.

The joints should be carefully dipped in or coated with a special liquid compound provided for this purpose, so as to insure water-tightness. The cables should be spaced about 1½ inches apart, by means of wooden separators; and the spaces between the ducts, and between the walls of the trench and the outer ducts, should be filled with a thin grouting of cement and sand. If more than one horizontal row of ducts are installed, the grouting of each row should be smoothed over so as to prepare a base for the next row of ducts.

To fish the conductors in fibre conduit, it is not necessary to follow the method of rodding usually required with vitrified conduits; but it is found that by utilizing a solid No. 6 iron wire, and fishing from one manhole to the next, the mandrels and brush can be attached to the end of the wire and pulled through the conduits, thus insuring that the joints are smooth and that there are no obstructions in the conduit. To prevent accidental clogging of the ends of the con-

duit, wooden plugs should be installed in the openings of all unfinished conduit work, or in all unoccupied cable ducts at manholes.

Drawing In the Cables. After the conduits have been tested by means of the mandrel to ascertain that they are continuous and that the joints are smooth, the work of installing the cables may be started. Special precaution should be taken to prevent sharp bending of the cables, and thus to prevent injury to the lead sheathing of the rubber insulation. If the cable is light and of small diameter, the distance not over 300 feet, and the run fairly straight, the cable can usually be pulled in by hand; but often other means must be provided so as to secure sufficient power. Precautions should be taken, however, to avoid placing too great a strain on the cables, as it is liable to injure them, and the injuries may not show up immediately, but may cause trouble later. The remedy is to avoid placing the manholes too far apart, and to have the runs as straight as possible; also to properly test the conduits for continuity and smoothness before starting to install the cables. Enough slack should be left in each manhole to allow the cables to pass close to the side walls of the manhole, and to have the centers free and accessible for a man to enter the manhole. Where there are a great number of cables in a manhole, shelves or other supports should be

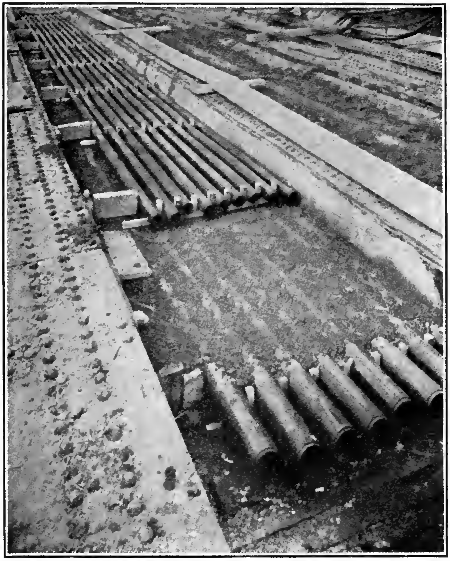


Fig. 77. Method of Laying Fibre Conduit in Trench.

provided for holding the cables apart and in position. Where two or more conductors are placed in the same duct, they should always be pulled in at the same time, for otherwise the cables last pulled in are apt to injure those already installed.

Manholes. Manholes should be provided about every 300 feet, in order to facilitate the installation of the conductors in the duct. The exact distance between manholes should be determined by conditions; in some cases they should be placed even closer together than the figure given, while in other cases their distance apart might be slightly greater.

Manholes are built of concrete or brick, and provided with a cast-iron frame or cover. The manholes may be of square, round, rectangular, or oval section, the last-mentioned form of manhole being probably the best, as it avoids the liability to sharp bends or kinks being made in the cable. The manhole cover may be of the same form as the manhole itself, or it may be of different form; but round or square covers are usually used. Fig. 78 shows a standard form of manhole used in New York City. This manhole is substantially built, and adapted for heavy traffic passing over the cover. For suburban or country work, manholes may be made of lighter construction.

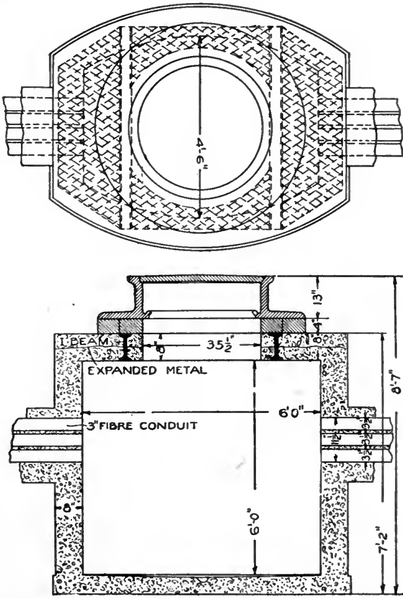


Fig. 78. Plan and Sectional Elevation of Standard Form of Manhole Used in New York City.

EXAMINATION PAPER

ELECTRIC WIRING

Read Carefully: Place your name and full address at the head of the paper. Any cheap, light paper like the sample previously sent you may be used. Do not crowd your work, but arrange it neatly and legibly. *Do not copy the answers from the Instruction Paper: use your own words, so that we may be sure that you understand the subject.*

1. Explain the three-wire system of wiring.

2. In case a test shows excessive leakage, or a ground or short circuit, how would you locate the trouble and remedy it?

3. Describe the construction and use of outlet-boxes.

4. What is the principal difference between alternating and direct-current circuits, so far as concerns the wiring system?

5. Compare the advantages of the two-wire and three-wire systems of wiring.

6. Under what general heads are approved methods of wiring classified?

7. A single-phase induction motor is to be supplied with 25 amperes at 220 volts; alternations 12,000 per minute; power factor .8. The transformer is 200 feet from the motor, the line consisting of No. 4 wire, 9 inches between centers of conductors. The transformer reduces in the ratio $\frac{2,500}{250}$, has a capacity of 30 amperes at 220 volts, and, when delivering this current and voltage, has a resistance-E. M. F. of 2.5 per cent, and a reactance E. M. F. of 5 per cent. Calculate the drop. (Use table and chart.)

8. What are the distinctive features of the different kinds of metal conduit?

9. Suppose power to be delivered, 300 K. W.; E. M. F. to be delivered, 2,200 volts; distance of transmission, 15,000 feet; size of wire, No. 00; distance between wires, 24 inches; power factor of load, .7; frequency, 100 cycles per second. Calculate line loss and drop in per cent of E. M. F. delivered. (Use table and chart.)

10. In installing A. C.-circuits, what requirements are insisted on as to the placing of conductors in conduits?

11. Describe the manufacture, use, and special advantages of the different kinds of armored cable.

12. Describe three different methods of testing? Which is to be preferred?

13. What conditions determine whether a two-wire or three-wire system of wiring should be used?

14. In locating cut-out cabinets and distributing centers, what requirements should be fulfilled?

15. What is "knob and tube" wiring? Explain its use and discuss its advantages or disadvantages.

16. How far apart should insulators be placed?

17. What tests should be made before an electric wiring equipment is finally passed for acceptance? Give reasons.

18. What regulations govern the use of fibrous tubing?

19. What is meant by mutual induction?

20. What are the advantages and disadvantages of overhead linework as compared with underground linework?

21. Describe and illustrate by sketches proper methods of supporting and protecting conductors.

22. Discuss the advantages of running conductors exposed on insulators.

23. Illustrate by diagram, proper and improper methods of grouping conductors of two two-wire circuits.

24. What dangers are inherent in the use of moulding? What precautions should be taken to avoid them?

25. Describe the proper methods of laying out branch circuits, (*a*) in fireproof buildings; (*b*) in wooden frame buildings. Give sketches.

26. What methods of installing wiring are best adapted for the following classes of buildings, (*a*) fireproof structures; (*b*) mills, factories, etc.; (*c*) finished buildings; (*d*) wooden frame buildings?

27. What is skin effect? Its bearing on the problem of wiring?

28. In selecting runways for mains and feeders, what precautions should be taken?

29. Describe the method of laying (1) vitrified conduit; (2) fibre conduit.

30. Give sketches showing proper and improper methods of guying poles.

31. About how far apart should manholes be placed?

32. What different kinds of ducts are used for underground linework?

33. What are the general requirements of poles as to dimensions and spacing?

After completing the work, add and sign the following statement:
I hereby certify that the above work is entirely my own.
(Signed)